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Qānūn al-Riyy: The Water Law of Egypt

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Introduction

The Savants of the French expedition to Egypt (1799 - 1801) argued that Egypt had no formal rules for controlling its flood recession irrigation system and that Egypt's form of floodwater discribution was no more than the product of happenstance and custom. They characterized the existing system as primitive and simple, haphazard and disorganized. It's interesting that from our present-day vantage point this perspective is so alive and well. When it comes to flood basin chains and their regulators, scholars are really more adamant today than ever before that Egypt's Islamic-era flood basin system was a very "simple" system.[1] Why should there have been a rule book then – or any sort of water law – when all one is doing is letting water in to basins contained by transversal dikes?

Compare the map (**Figure 1**) with the basin-chain diagram that follows (**Figure 2**).

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[1] There are some nuances to this theme: Karl Butzer pointed out reasonably and recently that though "the basin-irrigation network may not have been properly maintained under the later Mamelukes…it was sufficiently effective that the industrial-era system could be grafted onto an existing base with comparative ease." Karl Butzer, "Geoarchaeological Implications of Recent Research in the Nile Delta," in *Egypt and the Levant Interrelations from the 4th through the Early 3rd Millennium B.C.E.*, ed. Edwin C M van den Brink and Thomas Evan Levy (London: Leicester University Press, 2002), 7-8, based on his critique of Ghislaine Alleaume,"Les systèmes hydrauliques de l'Égypte pré-moderne. Essai d'histoire du paysage," *Itinéraires d'Égypte: Mélanges offerts au Père Maurice Martin S.J.*, ed. Christian Décobert and Maurice Martin (Cairo: Institut Français d'Archéologie Orientale, 1992), 301-322.

Figure 1. Flood Basins, Upper Egypt, c. 1800

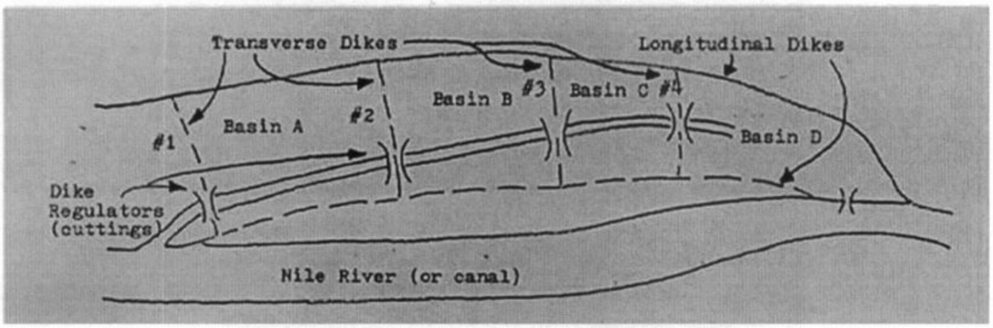


Figure 2. Flood Basins, Upper Egypt, c. 1880

The former is from the Napoleonic Description de l'Egypte, the latter based on the Willcocks-era of the late nineteenth century. The difference is rather striking: the former is haphazard and spells oral custom and rule of thumb, while the latter is well-ordered and suggests a written rulebook.

In this paper I will discuss the fact that there was indeed a rulebook in the Islamic era, a written water law (the Qanūn al-Riyy) (see **Figures 3** and **4**). It functioned and was enforced in the north-west Nile Delta province of Buḥayra/Ḥawf Ramsīs. This rulebook was aimed at something fairly sophisticated in quantitative terms: it imposed a system of rotating water usage via the controlled opening and closing of village dams. The purpose of this system of rotation was to regulate and maintain the velocity of water in village feeder canals. I'm going to talk about this rule book, how it worked, how it has performed in quantitative simulations and finally, the power apparatus it called into being - a coercive provincial administration.

Sources

The rules for Egypt's water law as they stood from approximately 404/1013 to 597/1200 are the basis for this study, though a number of medieval Arabic sources have provided

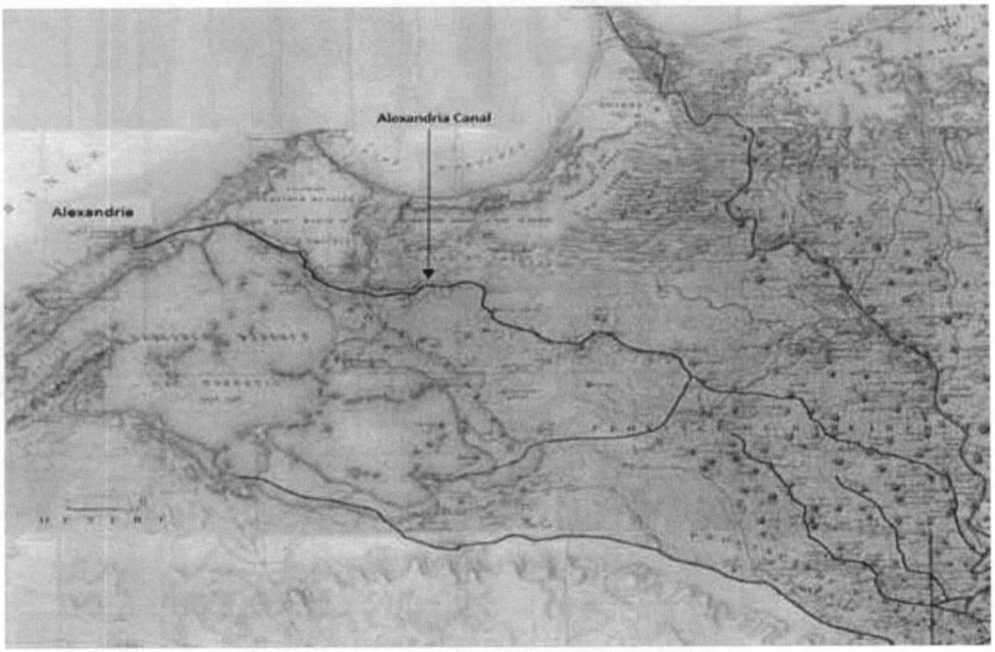


Figure 3. The Canal System of Buḥayra - Ḥawf Ramsīs c. 404/1013 – 597/1200 (canals set against maps from Napoloeonic expedition to Egypt, 1799-1801)

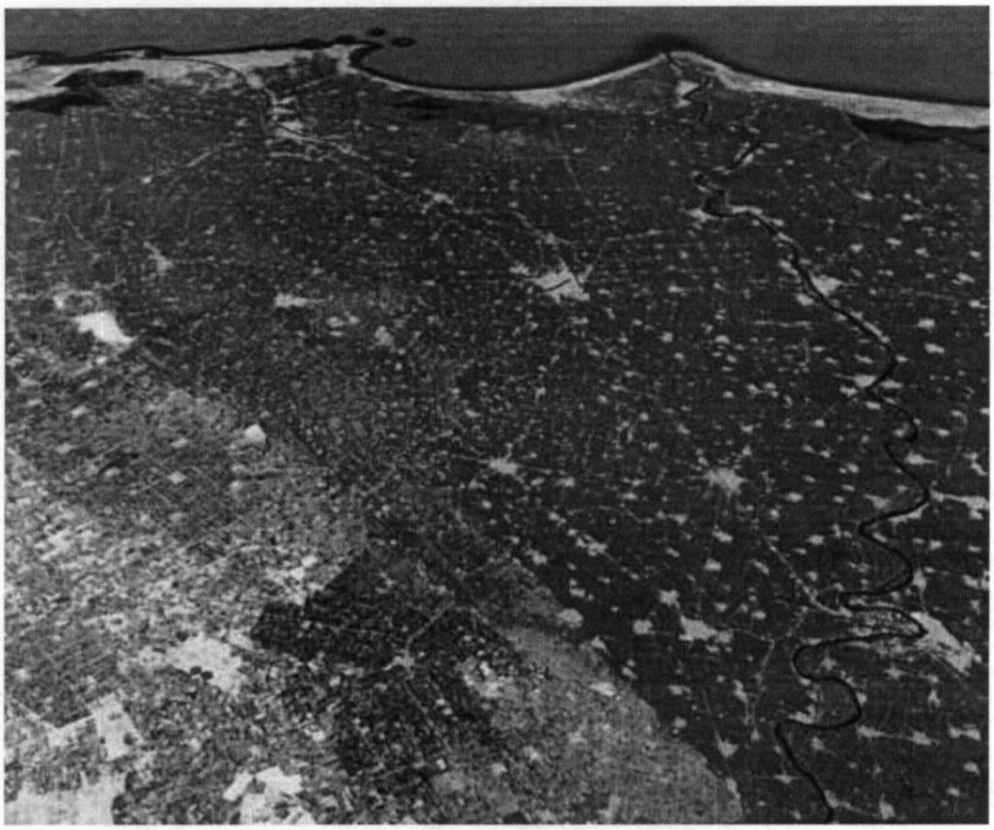


Figure 4. Al-Buḥayra: The track of the Alexandria canal (404/1013 – 710/1310, dashed) in red, Baḥr Damanhūr (dotted) in dotted red and Rashīd (Rosetta) branch of the Nile in blue (right-hand side, solid)

context and explanations for how implementation was effected. The bulk of the written rules that we have are for the north-west Nile Delta province of al-Buḥayra (known for the period in question as two provinces, (lesser) Buḥayra, to the north, and Ḥawf Ramsīs, to the south). The first of two texts containing these rules is that of Abū al-Ḥasan ʻAlī ibn ʻUthmān al-Makhzūmī (d. 1189), *Kitāb al-Minhāj Fī ʻIlm Kharāj Miṣr*. Though a large portion of al-Makhzūmī's original work was discovered decades ago, his discussion of the Qanūn al-Riyy survives only as quoted in al-Maqrīzī's writings from the first half of the fifteenth century.[2] Al-Makhzūmī (d. 585/1189) was the head of the Egyptian government's *dīwān al-majlis* at the end of the Fatimid period and beginning of the Ayyubid period. In 565/1169-70, he wrote his agricultural treatise, *al-Minhāj*, to which he made revisions and added some material around 580/1184-5. Al-Makhzūmī's book contains a great deal of information about agricultural practices, but also a detailed catalogue of how the Qanūn al-Riyy functioned in his time.

The second source of this information is ʻAsʻad bin Mammātī, who wrote at roughly the same time as al-Makhzūmī.[3] Ibn Mammātī's text differs from that of al-Makhzūmī in its format and in some of the details. It is not certain which of the two texts is the earlier one, though there are numerous cues about how the system had been altered over what was

[2] Ṭāqī al-Dīn al-Maqrīzī (d. 1442), *Kitāb al-mawāʻiẓ wa'l-iʻtibārbi-dhikral-khiṭaṭ wa'l-āthār* (Cairo: Bulaq Press, 1853-1854), 1: 169-71. For a long time the only known source for this treatise was a lengthy quotation by al-Maqrīzī in the fifteenth century, but in the 1960s, Claude Cahen discovered a manuscript in the British Library. For the sections of *al-Minhāj* that were found by Claude Cahen (British Museum MS. Add. 23, 483), see Abu al-Hasan ʻAli Ibn ʻUthman Makhzumi, *al-Muntaq'a Min Kitab Al-Minhaj Fi ʻIlm Kharaj Misr* / Claude Cahen, *Mulhaq Hawliyat Islamiyah*; Al-ʻadad Raqm 8; Variation: Supplément Aux Annales Islamologiques, Cahier No 8 (Cairo: Institut Français d'Archéologie Orientale, 1986). There are a great number of corruptions in names, some of their actual name changes over the long course of time, but many of them cases of copying. It is not clear where al-Makhzūmī obtained his information, whether from one of the functionaries at the ministry, or a local inhabitant of the province, or from another written source. We can say for certain that the earliest date for his detail was 404/1013-1014, i.e. we know that al-Makhzūmī's account contains information about an east-west line of the Alexandria canal that connected the area near Fīsha Balkhā (in the east) with the region of Qarṭasā and Damanhūr (in the west), and that this line was built by the Fatimids at that date. The latest conceivable date would assume that al-Makhzūmī added this *Qanūn* section when he made revisions in 580/1184-5. Thus the source of this information lies in an interval of less than two centuries, and probably during the rule of the Fatimids (969-1171 CE).

[3] Al-Asʻad Ibn Mammātī, *Kitāb Al-Qawānīn Al-Dawānīn* (Cairo: al-Jamʻīya al-Zirāʻiya al-Malakīya, 1943), 223-229. Ibn Mammātī came from a very prestigious Coptic Christian family (originally from Asyūṭ in Upper Egypt), a family that had enjoyed power and prestige in top positions in the Fatimid bureaucracy. His grandfather, Abū Malīḥ, had served as an administrator for the Fatimid Caliph Mustanṣir (d. 1094). His father, Muhadhdhab ibn Abū Malīḥ Zakarīyā (d. 1182 CE), known as al-Khaṭīr, had converted to Islam during a wave of anti-Christian polemic in the 1170s. When Ibn Mammātī came into his family inheritance, he took charge of the Dīwān al-Jaysh as secretary and general intendent (mustawfī), the post that had been occupied by this father and grandfather before him. Ibn Mammātī served in this position for the Ayyubid sultans Salāḥ al-Dīn (1169-1192) and al-ʻAzīz (1193-1198) and built up a strong reputation, not only for his administrative skills (he eventually became the head secretary, Naẓar al-Dawāwīn, for all of the Egyptian government diwans), but also for his literary talents. His *Qawānīn al-Dawāwīn* is the legacy of his in-depth knowledge of the medieval Egyptian bureaucracy. The expressed purpose of this book was its commission to serve as a guide for bureaucrats, clerks, and other agents of the ruling regime. As these administrative officials were supposed to be well versed in and have substantial knowledge of a wide range of subjects such as landed estates (*iqṭāʻ*) and their revenue (*ʻibra*), taxation in general, agricultural products, geography, and, of course, irrigation. The original, now lost, *Qawānīn* occupied four large volumes, and what survives is but a bare remnant, a summary of the original. But this work, a product of his family's long service to the Fatimid state, is nonetheless impressive and stands as a testimony to the skill and knowledge of the medieval Egyptian bureaucrat. See *Qawānīn*'s introduction by ʻAzīz Sūryāl ʻAṭīya, 1-31; idem, "Ibn Mammātī" in Nagendra Kr Singh ed., *Encyclopaedic Historiography of the Muslim World* (Delhi, India: Global Vision Publishing Ho, 2004), 413-414; *ثلاث شخصيات في التاريخ: ابن* .حمزة، عبد اللطيف *المقفع، صلاح الدين بطل حطين، حكم قراقوش*, 2000 ,الهيئة المصرية العامة للكتاب: 43-53; Richard Cooper, "Ibn Mammati's Rules for the Ministries: Translation with Commentary of the Qawanin al-Dawawin," Ph. D Thesis (Berkeley: University of California: 1973), 9-13.

probably a short space of time.[4] For Ibn Mammātī, we have much more information about the context of his work, where it concerns the irrigation system itself. The notes that Ibn Mammātī's made about his research say something about the irrigation system's structure and scale. Ibn Mammātī explains to the reader that he tried very hard to get a comprehensive grasp of the Nile Delta's irrigation systembut – due to the complexity and size of the system – he had to limit his analysis and compilation to the larger-scale components in the system that were under the authority and care of the state (dawla).[5] Nevertheless, there is abundant detail. In fact the catalogue of irrigation components he assembled for just one of the Delta's provinces (al-Gharbiyya) runs to 117 large dikes, dams, and weirs.[6] Furthermore, what is remarkable about his details are that they were subject to not one but two abridgements, a doubled shortening (iqtaṣār) that leaves the reader wondering just how much detail Ibn Mammātī actually saw amid the documents of state (ḥisāb al-mustakhdimīn).[7]

I. Qanūn al-Riyy

What was the Qanūn al-Riyy in practical terms? The term was used in more than one fashion over its long association with irrigation and agriculture.[8] If one excludes the

[4] I propose that both he and al-Makhzūmī are transcribing or reading from a third source. Linda Northrup suggests this possibility. See Linda Northrup, *From Slave to Sultan: The Career of Al-Manṣūr Qalāwūn and the Consolidation of Mamluk Rule in Egypt and Syria (678-689 A.H./1279-1290 A.D.)* (Stuttgart: Steiner Verlag, 1998), 255-256. However, comparison between al-Maqrīzī's rendition of al-Makhzūmī and that of Ibn Mammātī's invites speculation here. Ibn Mammātī's version of the *qanūn al-riyy* for the basin chain of *Bahr Damanhūr* and the basin chain of *Baḥr Ramsīs* might be older than the al-Makhzūmī version. To begin with, the area is explicitly referred to as *Ḥawf Ramsīs*. Ibn Mammātī's version of the Ramsīs basin chain also stops at *Abū Ḥumār* and *al-Buhūṭ*, and, following instructions for the *Baḥr Damanhūr* then takes up a very different set of conditional clauses and provisional instructions that involve the controlled sharing of floodwater between the *Baḥr Ramsīs*, the *Tur'a Tabarīna*, and the *Baḥr Damanhūr*. Conditional "if/then" clauses reflect the specific temporal and geographic nature of this setting. Ibn Mammātī, op.cit., 225-227.

[5] Ibid., 206.

[6] Ibid., 209-217.

[7] Ibid., 206. That is that not only does Ibn Mammātī shorten the list to sultani components, but a later copyist eliminates most of those as well. See copyist notes included by the editor (note 5 in Ibid., 206). As for the sulṭānī/baladī division, Egypt's irrigation system fell into two categories. The first of these, the baladi system, was the local, village-level system. It was everything, as al-Qalqashandī put it, "inside the boundary of the village." (Ahmad ibn 'Ali al-Qalqashandi, *Subh Al-A'shā Fi Sina'at Al-Insha* (Cairo: al-Muassasah al-Misriyah al-'Ammah lil-Talif wa-al-Tarjamah wa-al-Tiba'ah wa-al-Nashr, 1964), 3: 516; Al-Ẓāhirī, Khalīl bin Shahīn, *Kitāb Zubda Kashf Al-Mamālik Wa Bayyān Al-Ṭuruq Wa Al-Masālik* (Paris: Imprimerie Nationale, 1894), 129; Ṭāqī al-Dīn al-Maqrīzī (d. 1442), op.cit., 1: 101). It was supposed to take care of itself and it was fundamentally dependent on a local, communally organized system of maintenance. (Tsugitaka Sato, *State and Rural Society in Medieval Islam: Sultans, Muqta's, and Fallahun*, Leiden: E.J. Brill, 1997, 183-184). The sultani system, by contrast, was everything the baladi system was not. It was outside the boundary of the village, it linked the villages together, it linked different parts of the system together, it linked one part of the baladi system to other parts of the baladi system, and it connected the baladi system, at most points, to the Nile River. (Ahmad Ibn 'Ali al-Qalqashandi, op.cit., 3: 515; Al-Ẓāhirī, op.cit., 129.)

[8] It seems that defining the Qanūn al-Riyy has been challenging. A number of scholars have asked: what was this "qānūn"? Does it relate to the landholding documents known as "qānūn al-riyy?" see Richard Cooper, "Land Classification Terminology and the Assessment of the Kharāj Tax in Medieval Egypt," *Journal of the Economic and Social History of the Orient/Journal de l'Histoire Economique et Sociale de l'Orient* 22, 1974, 371.

"The qānūn al-riyy, on which the administrator relies, lists all the irrigated lands." This is according to Cooper (1974, 371), where he continues by saying "it lists the total acreage of the system which is irrigated and subject to the kharāj." And, "after the qānūn al-riyya is submitted, the civil servant compares it to a similar year of the Nile flood. Then he allocates it - yuḥaḍḍiru (cf. taḥḍīr) to the cultivators in a way analogous to how it was allocated in a comparable Nile year. See Ibn Mammātī, op.cit., 205-232; al-Maqrīzī, op.cit., 1: 61, 171; Cooper, 1974, 397.

meanings that were more particular to agriculture than irrigation per se, the Qanūn al-Riyy indicated in very general terms the fashion in which the irrigation system was to be operated. Recent work on Ottoman Egypt, its irrigation system, and the rural courts, indicates that the Qanūn as a broad concept was deeply embedded into the heasts, minds and legal rulings of the rural community in all of its dealings with water. However this Qanūn does not seem to have entailed at all times a formal written rulebook. As Mikhail notes of Ottoman Egypt, "The Qanūn is not cited as an "official" body of legal writing but is rather invoked by parties at court and by judges themselves as precedent." Mikhail notes the use of the term min qadīm al-zamān, or "times of old." As a reference to custom and precedent.

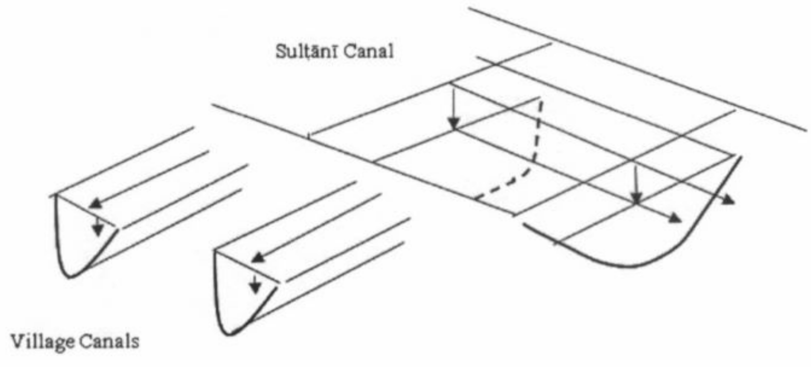
What I will argue is that during the latter part of the Fatimid/early Ayyubid period, the Qanūn al-Riyy was a hydraulic imperative consisting of a series of written orders governing water flow. These orders mandated that water usage be rotated, each user taking a turn in sequence, so that village feeder water demand upon sulṭānī canals (like the Alexandria canal) be kept below a certain threshold. This threshold itself was where water demanded (demanded by village canals) became so great that the height in channel of the supply canal (supplied by a sulṭānī canal) fell far enough that village canals were effectively unable to draw from them anymore. My conclusiosn were made from examining the two texts for the Qanūn al-Riyy in the context of schematics of sulṭānī canals in Buḥayra and applying the Chezy-Manning equation and a curvelinear regression (below, in diagram) to two hydraulic scenarios, which were compared in computer simulations. These two hydraulic scenarios were respectively:

1. The Qanūn al-Riyy was ignored: water usage was not controlled – and aggregate village water demand rose to levels at which the sulṭānī canal supply was rendered effectively useless as a supply channel.
2. The Qanūn al-Riyy was implemented: water usage was controlled and demand kept below a certain threshold by rotating the opening of village dams.

The quantitative computer simulation programs indicate that the medieval Qanūn al-Riyy of Islamic Egypt offered the solution to a very serious problem for the village irrigation systems that fed from long transverse canals like the Alexandria canal. A schematic for this system is shown below, along with equations that were used in the simulation (**Figure 5**).

Ⅱ. Schematic (Showing Junctions of Canals)

There is abundant evidence from the Mamluk era for how this problem played out on an even larger scale, via the aggregates of sultani canals feeding from the Nile itself. Alan Mikhail's archival research into the rural court records of Ottoman Egypt, records that served as a kind of common law of precedents for the Qanūn al-Riyy, gives evidence for the manifestation of this problem at the level of sulṭānī-baladī (village) canal supply and



$$V_{f_l} = (W_c)\frac{1}{n}(S_o)^{\frac{1}{2}}\left(\frac{((4.5E-4 \cdot V_f{}^3)-(2.6E-2 \cdot V_f{}^2)+(.65 \cdot V_f)+(.40)-2.75)W_c}{2((4.5E-4 \cdot V_f{}^3)-(2.6E-2 \cdot V_f{}^2)+(.65 \cdot V_f)+(.40)-2.75)+W_c}\right)^{\frac{2}{3}}$$

Figure 5. The Equation for volumetric flow (composed of the Chezy-Manning relationship and a regression equation) through village canal ($y = V_{fl}$ at left) feeding from a major sulṭānī canal (main channel at center) with volumetric flow ($x = V_f$ at center)

demand. What Mikhail concludes from his analysis of court records is that the problem was as common as were its dire consequences, wherein "too many canals were opened on a central artery of water thus draining this main channel to a point where it was rendered unusable for irrigation."[9]

Ⅲ. Water Rotation

It is apparent from the texts of the Qanūn al-Riyy that "rotation" can be understood in more than one way. The simplest form of rotation was a means for controlling water demand by the sequential opening of enormous sulṭānī dikes that separated one flood basin from another in long basin chains. These basin chains followed the trajectories of large-scale sulṭānī canals, like the Baḥr Ramsīs, the Baḥr Damanhūr, or the Khalīj Ṭayriyya, that ran in transverse fashion relative to the Nile (see diagram below). Relative to these transverse canals, the sulṭānī dikes that contained the water on the upstream and downstream sides were effectively longitudinal dikes. Understood in this fashion, these long basin chains (Baḥr Ramsīs/ 35km, Baḥr Damanhūr/30km, Khalīj Ṭayriyya/40-70km) should be seen as the equivalent of the Willcocks' era basin chains in the Upper Egypt of the late 1800s. In that sense their existence in medieval Islamic Egypt serves as a corrective to the viewpoint that the system of Islamic Egypt was crude and simple.

The example of the Baḥr Damanhūr allows us to study one of these basin chains via the text of the Qanūn al-Riyy. The Bahr Damanhūr was a line of four enormous flood basins that stretched some 30 kilometers from the vicinity of Damanhūr down to the shores of the Maryūṭ lagoon. Though its existence is not recognized on Toussoun's maps, its track can

[9] Mikhail translates the Ottoman Turkish term for sea, deniz, to the Arabic baḥr. Alan Mikhail, *The Nature of Ottoman Egypt: Irrigation, Environment, and Bureaucracy in the Long Eighteenth Century* (Berkeley: University of California, 2008), 47.

be clearly read from the Qanūn al-Riyy and maps of village locations. The Baḥr Damanhūr took its water from the Alexandria canal and fed the water downstream and south-westward until it emptied into the Maryūṭ Lagoon. The existence of the Baḥr Damanhūr is demonstrated by the fact that the Qanūn al-Riyy places its mouth at the villages of Iflāqa and Asknīda at Damanhūr – and that the ruined track of this canal can be seen on at this exact point on a map from the Napoleonic expedition (see **Figure 6**):

المقريزي (*الخطط 1: 170*)
تراع بحر دمنهور يفتح في العشرين من مسرى إلى سادس توت
و يروى منها بعض طاموس, و بعض كنيسة الغيط, و قرطسا و دمنهور...
... و اما بحر دمنهور فإنه يسد على سلطيس إلى سابع عشر توت
و منه تشرب سلطيس و زهرا وبعض طاموس و بعض قرطسا و بعض كنيسة الغيط ودمنهور
ثم يقطع سد نديبة و هو محدث فيقيم هناك الماء ثمانية أيام و منه تشرب نديبة و دقرس والعميرية و النسرين.
ثم يفتح و يسد على محلة خفص و محلة كيل و محلة نمير
ثم يقطع سد سلطيس و هو محدث فيقيم عشرة أيام بعد اختلاط المائين ببحر دمنهور وبحر رمسيس
ثم يقطع جسر ملولة و منه تشرب تروجة و أرسيس و المراسى و غابة الأعساس و بعض سمرو و محلة نمير ويبقى هناك إلى إنقضاء النيل.

Translation

"The canals that feed off of the Damanhūr canal are kept open from the 20th of Misrā (19 August) to the 6th of Tūt (9 September). Floodwater is supplied to irrigate sections of Ṭāmūs, Kanīsat al-Ghayṭ, Qarṭasā – and Damanhūr … [break in text] … the Damanhūr canal is dammed at Sunṭays (dike) until the 17th of Tūt (20 September). Floodwater is supplied to the Sunṭays andthe Zahrā village district areas and to (sections of) Ṭāmūs, Kanīsat al-Ghayṭ, Qarṭasā and Damanhūr areas. The Nadība dam (of recent construction) is then cut/broken open. The floodwater is retained there for eight days. Water is supplied to areas of Nadība, Diqris, al-'Amīriyya, and al-Nisrīn. The dike for the next basin is then cut/ broken open and dammed shut to supply floodwater to the village districts of Maḥallat Ḥafṣ, Maḥallat Kīl, and Maḥallat Numayr. The Sunṭays dam (of recent construction) is then cut/ broken open and the water is held there for ten days, whereby the waters of the Damanhūr canal and the Ramsīs canal are allowed to mix. The Malūla dike is then cut/broken open and the following village areas are provided with floodwater: Tarūja, 'Arsīs, al-Marāsī, Ghābat al-'A'sās, (sections of) Samrū and Maḥallat Numayr. And the water is held there until the Nile flood recedes."

Taking cues from this text, and looking at the issue of rotation in general terms, it might seem reasonable to assume that rotating usage was no more than the application of fair water usage principles with one of its purposes being the prevention of strife and conflict over water. Naturally this was an issue, and the just use of water was indeed one of the concerns (and in fact that is part and parcel of the bigger picture of irrigation control). However the real objective was a concerted effort to maintain water velocity in the feeder

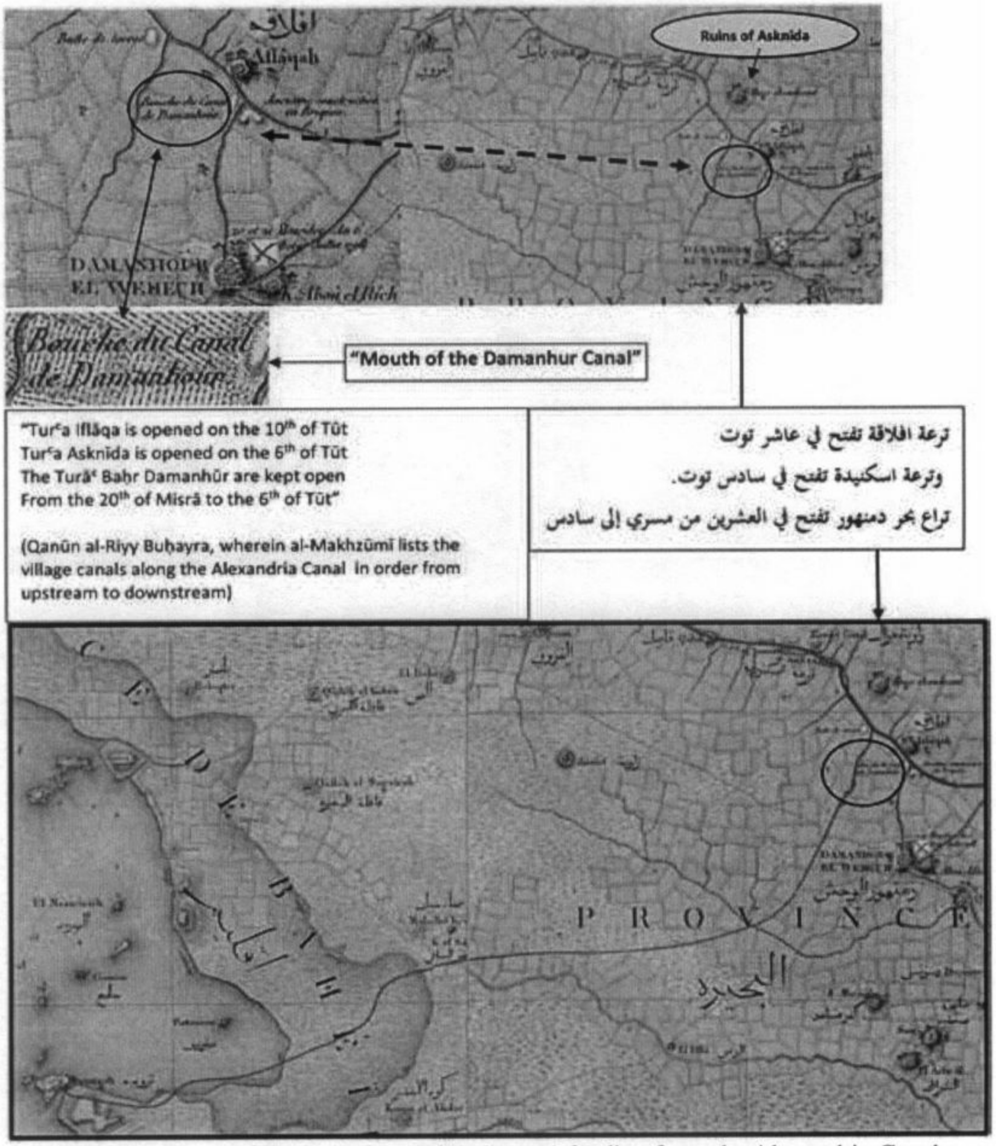


Figure 6. Trajectory of the Baḥr Damanhūr (center) feeding from the Alexandria Canal (upper right) against maps of the Napoleonic expedition

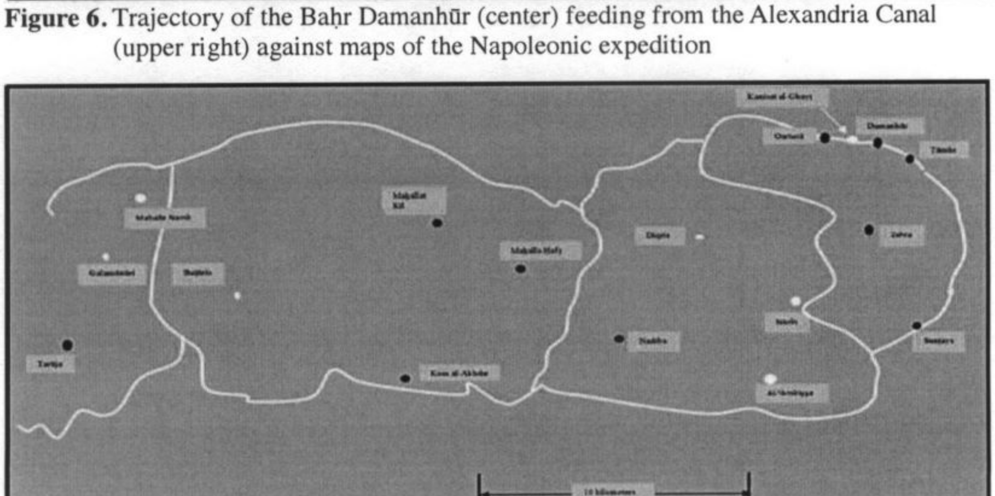


Figure 7. Plot of village locations and plausible basin boundaries via village locations Sketch by author based on Google Earth

dams to village systems.[10]

As heights in feeder canal channels (i.e. depth of water in the village canals) would plummet when too many villages opened their dams at the same time, water velocity and volumetric flow were vulnerable to what was in essence the overuse of a common resource, a sort of tragedy of the commons.[11] As will be seen in the quantitative simulations below, the systems of rotation presented by this document was designed to lower aggregate water demand placed on the sultani canals, and thereby solve a very troubling issue for the long canals and their multitude of village irrigation systems. The 120 kilometers of the Alexandria canal had as many as 140 villages systems feeding from it in the early Mamluk period; other canals in the province of Buḥayra, the Baḥr Ramsīs and Khalīj Ṭayriyya for example, had a similar number of systems feeding from their channels.

Computer simulations show that the Qanūn's hydraulic scheme, its coordinated plan of action, was an effective and cleverly engineered solution to the glaring problem of falling water velocities. The schedule for Buḥayra, our only complete (or nearly complete) blueprint from Egypt's water law is detailed via the schematics below. The focus is the Alexandria canal, the water usage for the Alexandria canal and the water usage of one of its branches, the Baḥr Damanhūr. The functioning of the Qanūn's rotation system for the Alexandria canal is shown below in a simplified scheme of seven rotations of the 76 listed village districts that fed from the two joined canals (**Table 1**). In fact there were more than seven rotations, as can be seen below.[12] The schematics and table below illustrate the sequences of rotation on the Alexandria canal and are followed by a description of the computer simulation.

The indications are that the villages along the Alexandria canal rotated the use of their dams in order to maintain adequate velocity in the village supply channels (baladī canals). Their dams drew water from the sulṭānī canal (Alexandria canal in this case) which in turn took its water from the Nile. Rotation was a practical if potentially complicated solution

[10] This concerns the same as in other eras: Ottoman, Ptolemaic, Roman. And in some cases the "state" did have some involvement in issues of just distribution, at least on the large scale end of the system, in its interconnections (the "Sulṭānī" system – or parts of it – as it was termed in the medieval and Ottoman periods). For the Romans there was concern for the proper distribution of water, and also an eye to preventing the misuse of water, such as deliberate diversion of canals in an effort to forestall tax obligations (i.e. to render a flood basin dry, sharāqī). See Fabienne Burkhalter, "Irrigation et production agricole en Égypte hellenistique et romaine," *Histoire, Économie Et Société* 16, 3, 1997, 343-352.

[11] See the discussion of Ottoman-era archival research below from Alan Mikhail, *Nature and Empire in Ottoman Egypt: An Environmental History* (Cambridge: Cambridge University Press, 2011).

[12] The rotation begins with the filling of Alexandria's cisterns. Nābulūsī, writing in the mid-1200s, informs us that the filling of cisterns begins when the Nilometer on Rawḍa Island (at Cairo) reads 13 cubits, though he notes that the water used to arrive at the city when the Nilometer read between 11 and 12 cubits. (This could simply be due to the process of silt accumulation on the bed of the Nile.) The Nile flood model indicates that for a mean flood c. 1200 the Nile would reach a height of 13 cubits on the 8th or 9th of August. See Charles A. Owen and C. C. Torrey, "Scandal in the Egyptian Treasury: A Portion of the Luma' al-Qawānīn of 'Uthaman Ibn Ibrāhīm al-Nābulusī: Introductory Statement," *Journal of Near Eastern Studies* 14 (2), 1955, 120-144.

What this means for the irrigation schedule can be calculated using Le Pere's estimate of the cistern capacity of the city of Alexandria, whereby he estimated that there were some 375 to 400 cisterns under the city, averaging about 161 meters cubed each in volume. If we take this as a general guideline, then even a relatively meagre flow through the canal would suffice to fill the city's cisterns within a time window of a couple of days, with leeway for any delays or mishaps. What this implies is that the city's water needs could be met first and foremost, as history seems to report, without interfering substantially in the province's irrigation needs. Albeit absence of urban drinking water would serve to make a much louder noise (in the short term) from a political point of view, the fact of the matter is that Alexandria's drinking water was a tiny drop in the bucket compared to al-Buḥayra's irrigation needs.

Date (Coptic)	Date	Alexandria Canal	Bahr Ramsis	Bahr Damanhur	Khalij Tayriyya	Khalij Ibn Zalum
15 Misra	14.Aug	388 Cisterns				
		161 m^3 each				
20 Misra	19.Aug	^	Begins filling 1st basin	Opening to Alexandria Canal	Jisr Shubra Wasim	open to Nile
		Opens 28 dams	S days		1st Basin	7
2S Misra	27.Aug		Open Jisr Dakduka		Jisr Dalinja	open 1st dike
			10 days		2nd Basin	7
1 Tut	4.Sep		Open Jisr Fatimi		Jisr	open Saft Khalid
		Opens 28 dams	S days		3rd Basin	
7 Tut	10.Sep		Open Jisr Disunis timm Dinar	Open Nadiba dike		drain
		Opens 20 dams	6 days	S		
17 Tut	20.Sep		Open Jisr Suntays	Open Suntays	drain	
				10		
27 Tut	20.Sep		drain	Open Malula/ drain		

Table 1. Simplified table for rotations in the province of Buḥayra

to a serious problem that bedeviled the long-canal system. As Mikhail's archival research has shown, this was a common problem that confronted the villages using the system, one that prompted response from the Ottoman authorities. In fact, the Ottoman authority that generally left so much of the running of the system to the villages did intervene in the matter of the timings for opening and closing village canals that fed from sulṭānī canals. Mikhail notes one of the examples wherein an Ottoman decree transmitted to the provincial court of al-Manṣūra (Daqhliyya-Murtāḥiyya) mandated that the dams of village canals feeding off of the Baḥr Saghīr (Ushmūn-Ṭannāḥ) were not to be opened until the volume of water in the canal had formed a sea.

Rotation was the solution and for the computer simulation, the principle equation used in the simulation was the Chezy-Manning solution for water velocity:

Water velocity (meters per second in the village supply canal) $= \frac{1}{n}(S_O)^{\frac{1}{2}}\left(\frac{H_C W_C}{2H_C + W_C}\right)^{\frac{2}{3}}$

Where the terms and principal dimensions are as follows.

(n) = the Manning constant/ the "roughness coefficient" (the texture of the canal's surface)
(S_O) = the canal's slope
(W_C) = the width of the canal
(H_C) = height in channel (depth)

Shown in the schematic below are three major canals of this province and a basic illustration of falling height in channel (depth) in a village supply canal taking water from the Alexandria canal. For the intersection of this large-scale sulṭānī canal (the Alexandria canal) and the 76 small-scale baladī (village) feeder canals we do have enough information to quantify the hydraulic scenarios in broad strokes at least. (We also have data on slopes

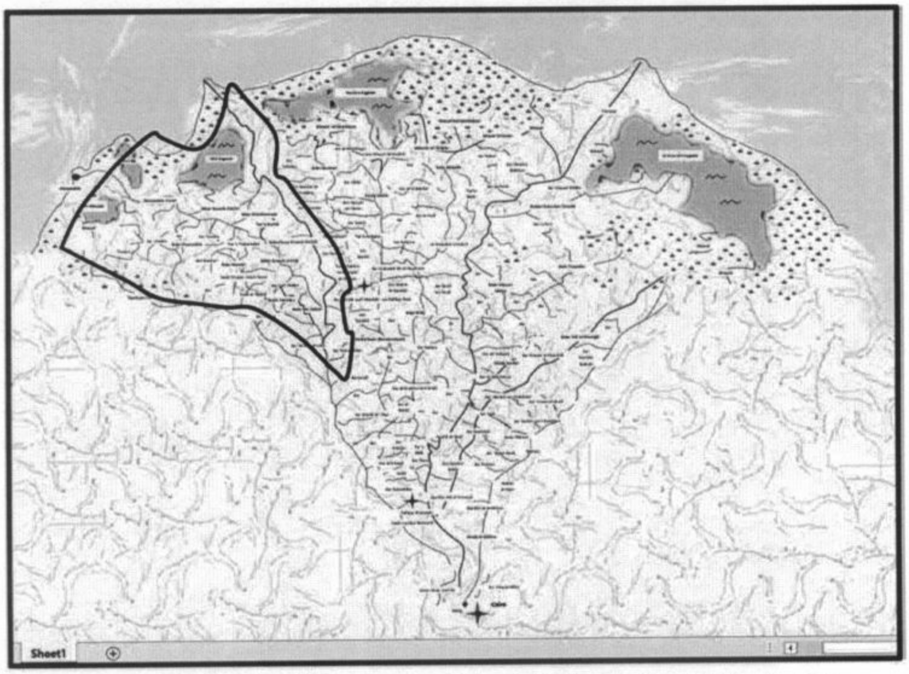


Figure 8. Nile Delta (showing irrigation components in the medieval Islamic era)

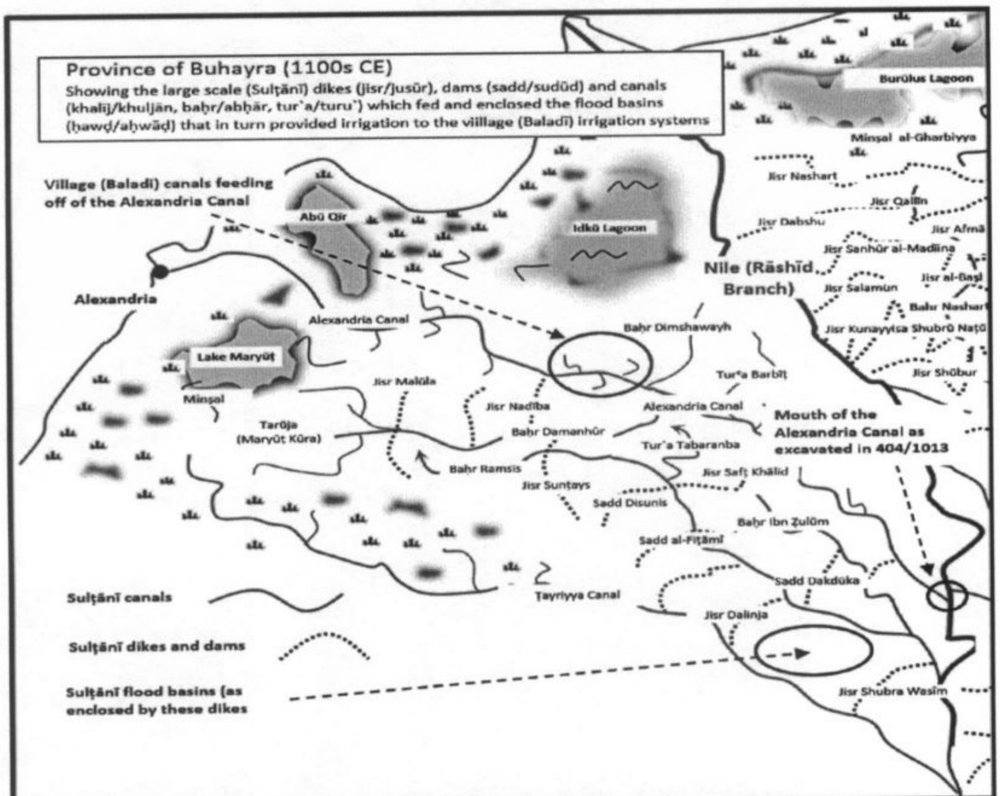


Figure 9. Province of Buḥayra (1100s CE)

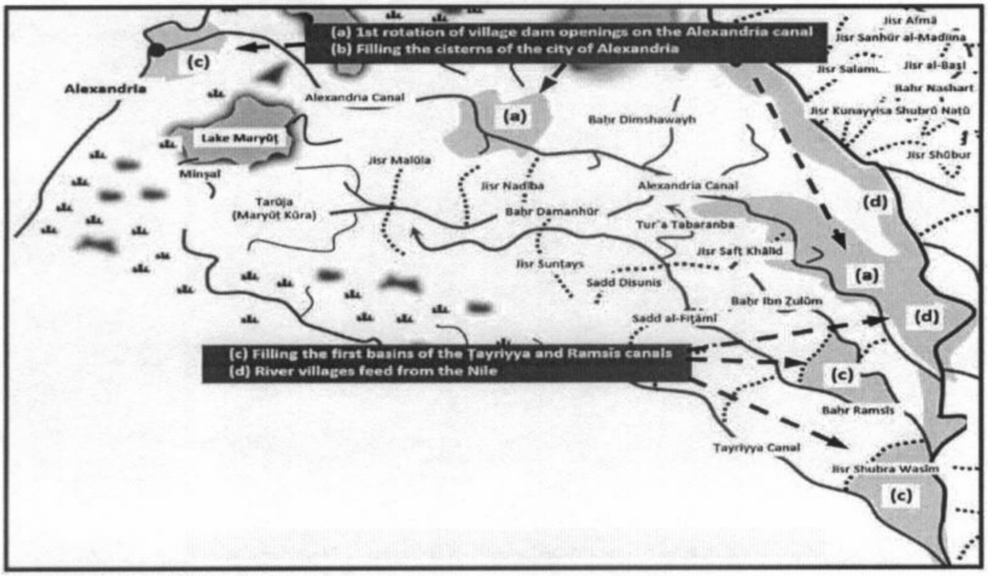


Figure 10. 15 Misrā (14 August) - or after the wafā' (16 cubits)

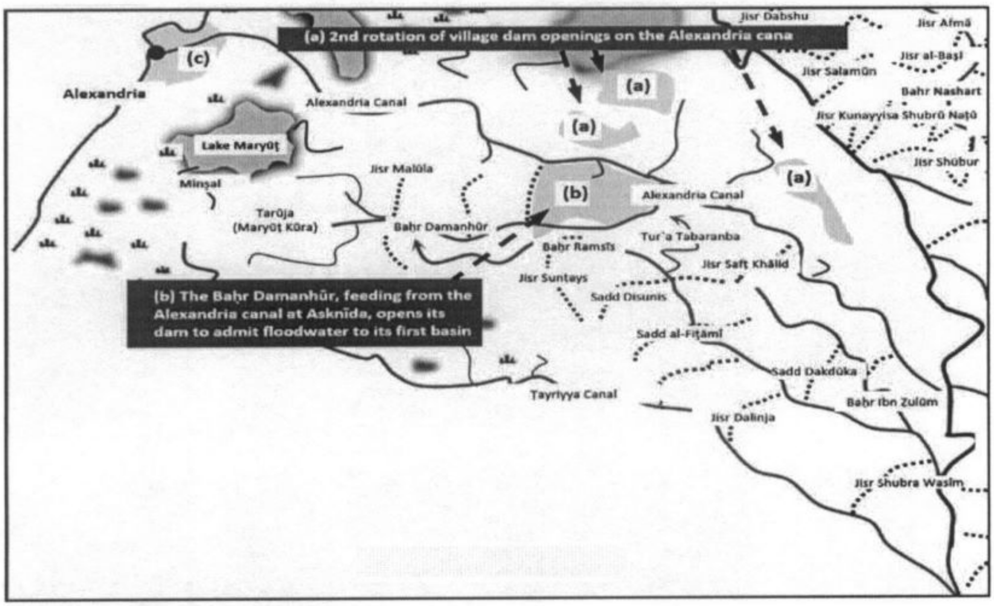


Figure 11. 20 Misrā (19 August)

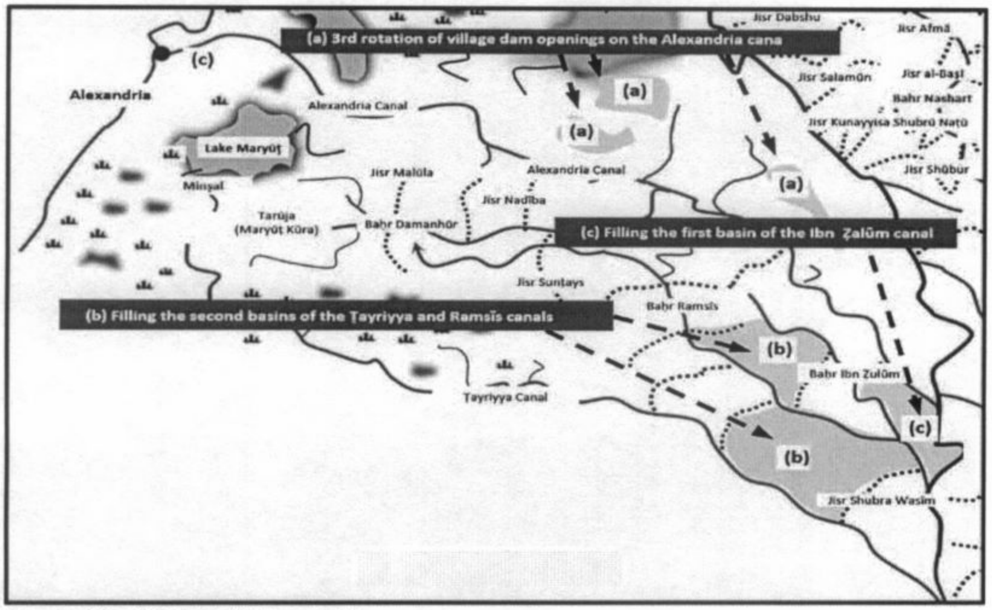


Figure 12. 28 Misrā (27 August)

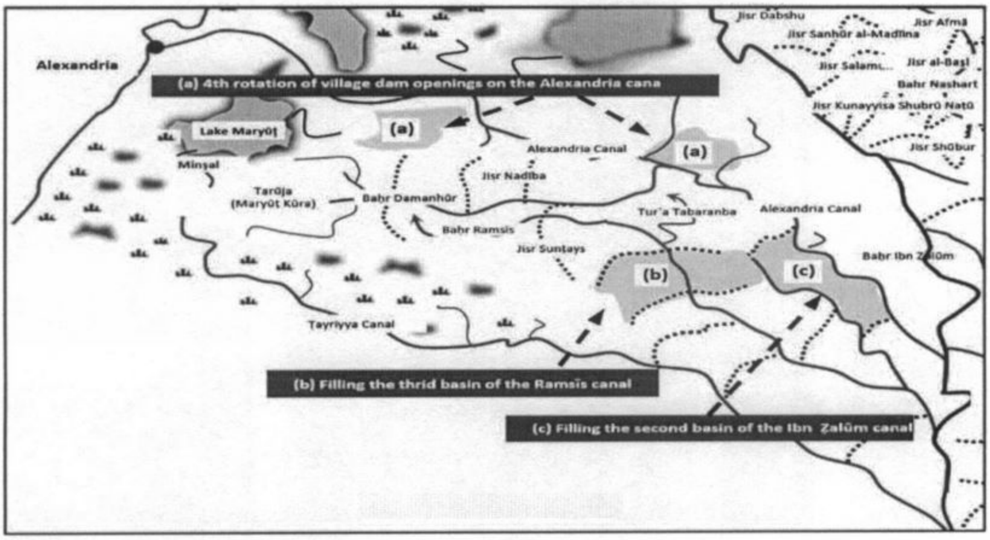


Figure 13. 1 Tūt (4 September)

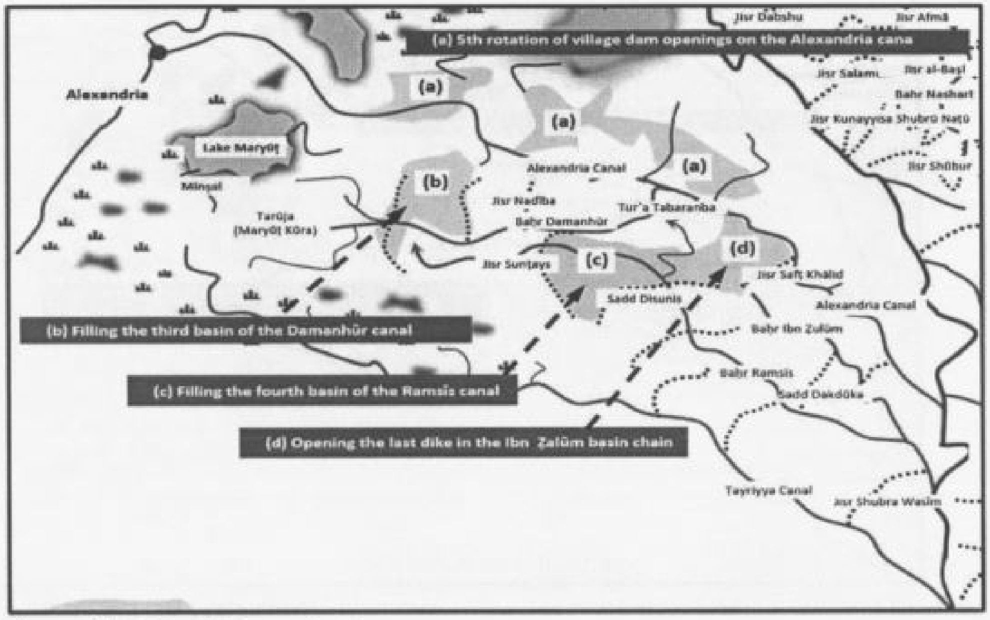


Figure 14. 7 Tūt (10 September)

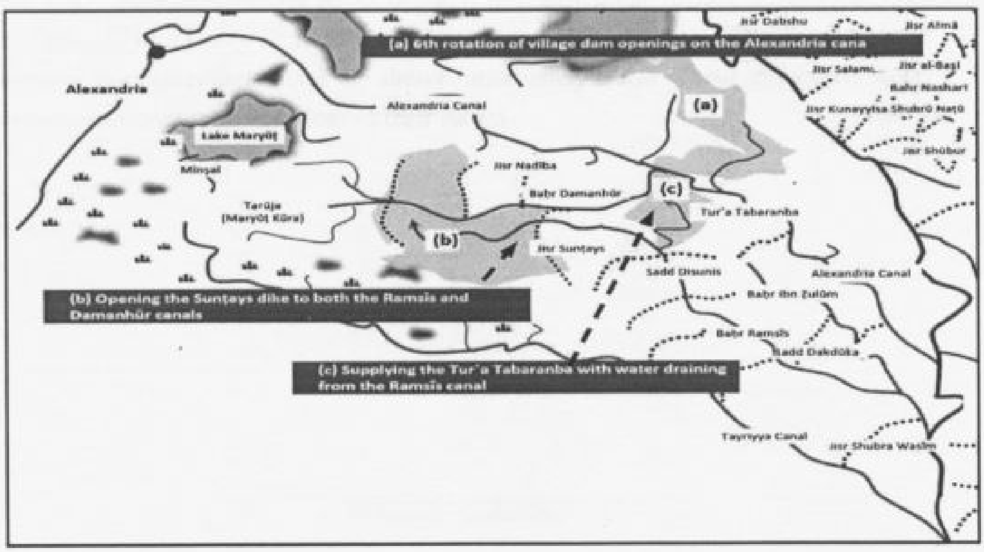


Figure 15. 17 Tūt (20 September)

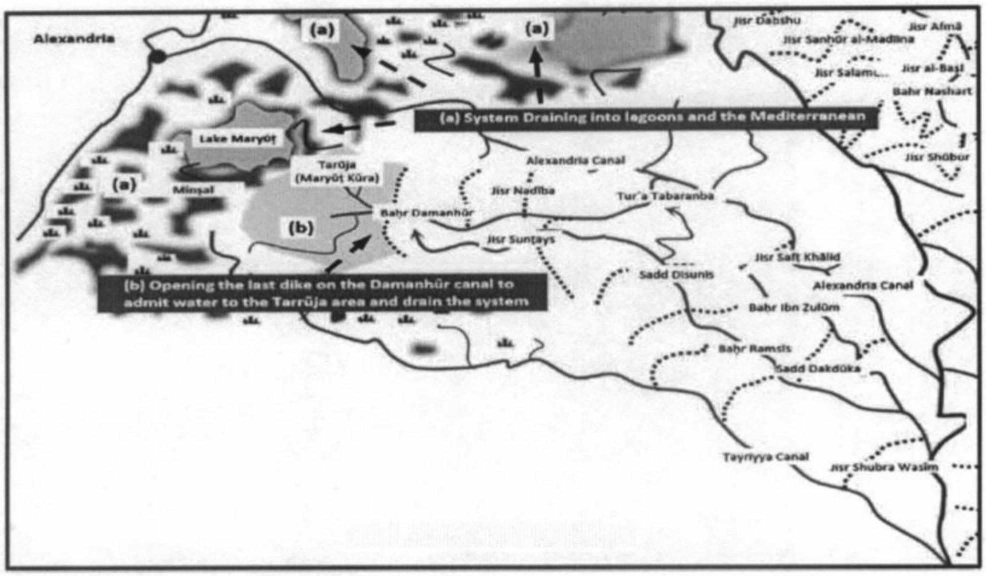


Figure 16. 27 Tūt (30 September)

and elevations (see **Figures 17** and **18**).[13]

We have some idea of the volume of the village basins, a rough sketch that we can take from the 1315 CE land surve (the Rawk al-Nāṣir of 1315 CE that measured the cultivable surface area (misāḥa) as well as averaged revenue values ('ibra)). The approximate parameters of the canals themselves are shown immediately below. These parameters were used in numerous tests with variations in their values.

[13] For discussions of Nile Delta subsidence, see Jean-Daniel Stanley, Andrew G. Warne, and Gerard Schnepp, "Geoarchaeological Interpretation of the Canopic, Largest of the Relict Nile Delta Distributaries, Egypt," *Journal of Coastal Research*, 2004, 920-930; D. J. Stanley, "Subsidence in the Northeastern Nile Delta: Rapid Rates, Possible Causes, and Consequences," *Science (New York, NY)* 240, 4851, 1988, 497; idem., "Recent Subsidence and Northeast Tilting of the Nile Delta, Egypt," *Marine Geology* 94 (1), 1990, 147–154; D. J. Stanley and A. G. Warne, "Nile Delta: Recent Geological Evolution and Human Impact," *Science-New York Then Washington* 260, 1993, 628; D. J. Stanley and A. G. Warne, "Nile Delta in Its Destruction Phase," *Journal of Coastal Research*, 1998, 795–825; Jean-Daniel Stanley, "Submergence and Burial of Ancient Coastal Sites on the Subsiding Nile Delta Margin, Egypt," eds. Christophe Morhange, Jean-Philippe Goiran, and Nick Marriner, *Méditerranée. Revue Géographique Des Pays Méditerranéens / Journal of Mediterranean Geography* 104, April 1, 2005, 65–73.

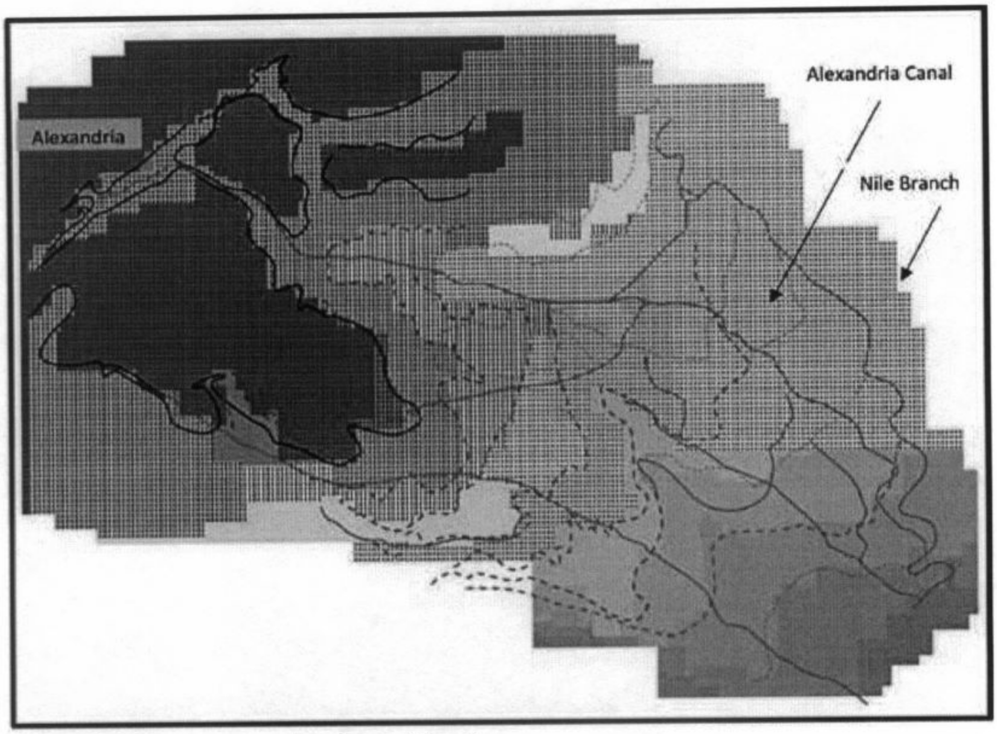


Figure 17. Contour map al-Buḥayra (Excel)

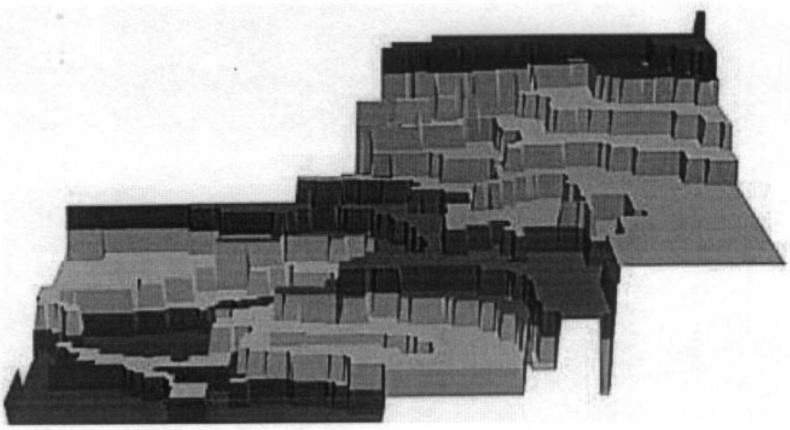


Figure 18. Contour graph of al-Buḥayra (Excel)

Sulṭānī Canal (the Alexandria Canal).[14]
Bottom width: 10 meters
Side slope: 2
Depth: 8.2 meters
Slope: $(\frac{1}{10{,}000})$
Manning constant: .22

Baladī (village) canals.[15]
Bottom width: 2 meters
Side slope: 2
Depth: 2 meters
Slope: $(\frac{1}{25{,}000})$
Manning constant: .22

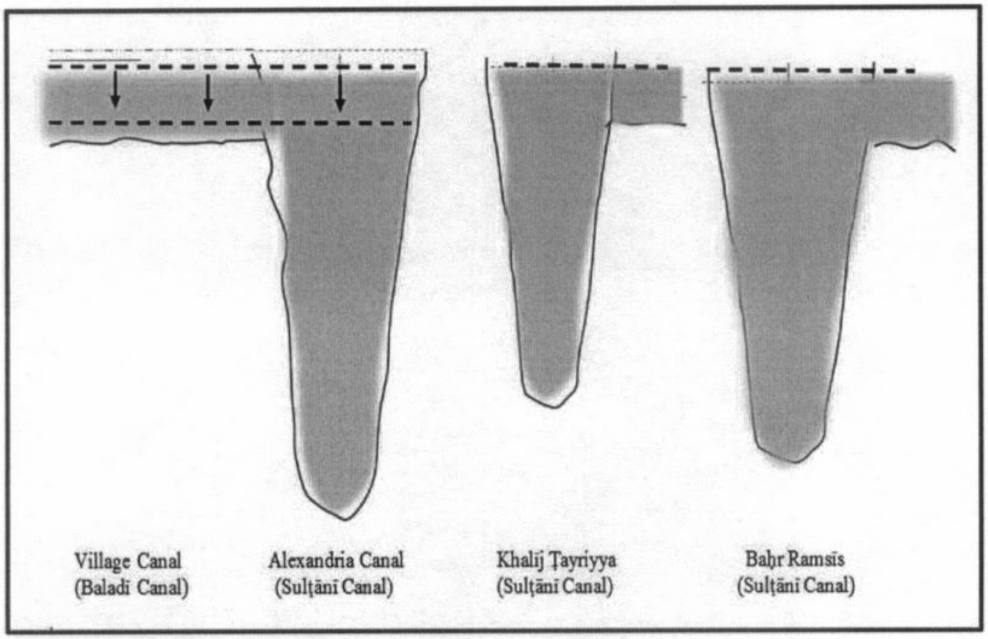


Figure 19. Major sultani canals of the Province of Buḥayra

The quantitative simulation program brought together the historical detail (the specific rules of the Qanūn – i.e. when each village opens and closes its dam, in what order, for how long), the geographic parameters (geocoding village locations, elevations, slopes), the hydraulic parameters (canal depth, bottom width, side slope, roughness coefficient),

[14] For the Alexandria canal, see Ibn Mammātī, op.cit., 221. Ibn Mammātī notes the following dimensions: 30,630 qaṣaba (~118 km) and depth (not listed) and width (2.5 to 3.5 qaṣaba average of 11½ meters [9.625 to 13.475 meters]). While depth is not listed, we can take a cue from the other large-scale canal that follows a trajectory with some comparable dimensions, the Khalīk al-Ṭayriyya, which was partially excavated in 1283 CE and had a reported width similar to the Alexandria canal (3-4 qaṣāba or about 13½ m) and a depth of 2.5 qaṣāba (about 10 meters) according to Ibn 'Abd -Zahir, Murād Kāmil, and Muḥammad A. Najjār, *Tashrīf Al-Ayyām Wa-Al-'Uṣūr Fī Sīrat Al-Malik Al-Manṣūr* (Cairo: al-Jumhūrīyah al-'Arabīyah al-Muttaḥidah, Wizārat al-Thaqāfah wa-al-Irshād al-Qawmī, al-Idārah al-'Āmmah lil-Thaqāfah, 1961), 25-26. Taking the depth-to-width ratio of the Tayriyya canal $(\frac{2.5}{3.5})$ and using the width given by Ibn Mammātī (11½ m) , we get a rough approximation of (8.2) to use in the simulation. There are a number of other reports concerning the dimensions (e.g. some 30.8 meters in width and 23.1 meters in depth) upon extensive re-excavation in 710/1310 according to al-Maqrīzī, op.cit., 1: 171), but the simulation used the dimensions above as they were representative of the state of the Alexandria canal in 1200 CE and earlier.

[15] 'Alī Mubarak's work in the 1800s indicates that the village feeder canals were commonly of dimensions 2 meters wide and a maximum of 2 meters deep. Comparisons with the village feeder canals of antiquity suggest similar dimensions during that era as well. They are reported to be (2 coudes (f~ 1.1 m) deep and 4 coudes (~ 4.3 m wide). The rest of the dimensions and parameters are discussed in the appendices. And from a comparative perspective, these dimensions are relatively generous. Rome's village feeder canals could be as shallow as (two Roman cubits .52m hence one meter) and as narrow as (four Roman cubits/ two meters), judging by papyrus records from the Fayyum. Burkhalter, op.cit., 343–352.

the Chezy-Manning relationship for water velocity and volumetric flow in open channels, and a nonlinear regression used to derive sulṭānī canal's volumetric flow from its height in channel. The input for simulation itself was from a model for the Nile flood which was used as the basis for calculating the height in channel of the sultani canal (the Alexandria canal). A graph from the Nile flood model can be seen here (**Figure 20**), with the flood season segmented into two halves. Al-Buḥayra belonged in the first half that stretched from roughly mid-August to mid/late-September.

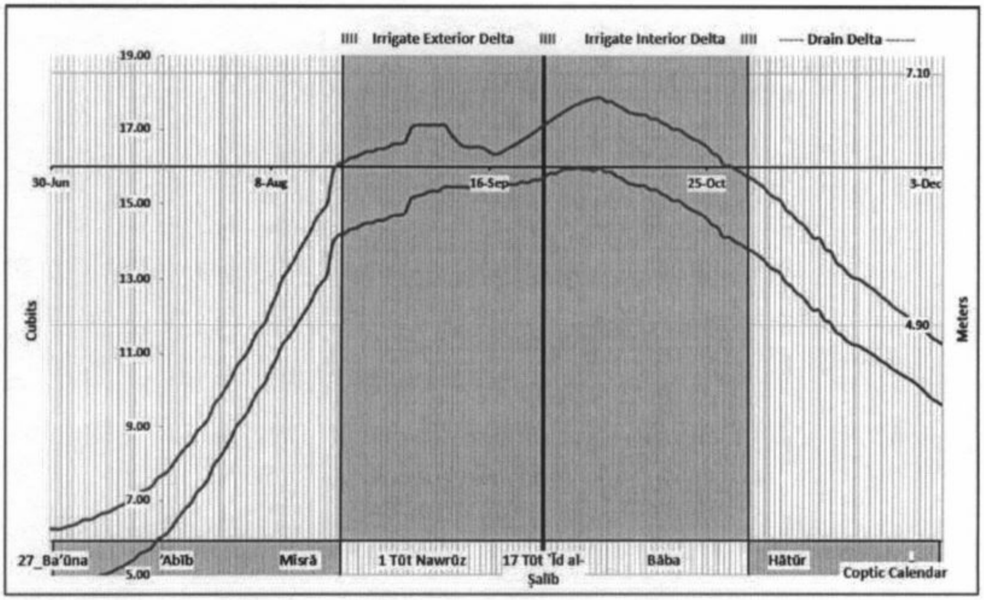


Figure 20. The Nile flood (June – Dec) with flood rise in cubits and meters

This height in channel of the Alexandria canal, for each day in the flood season, was quantified by the Nile flood model and a calculation for the intersection of the Nile flood and the Alexandria canal at Minyat Babīj (later, al-Ẓāhiriyya then al-Ḍaḥiriyya) on the western side of the Rashīd (Rosetta) branch of the Nile.

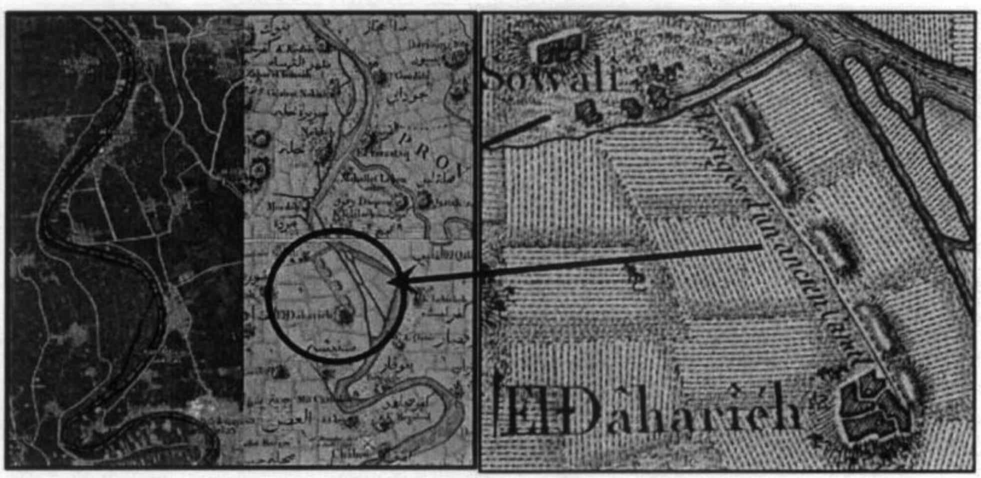


Figure 21. Napoleonic and present-day satellite images with closeup (at right) of the "vestiges d'un ancient canal" (the old mouth of the Alexandria canal (404/1013 – 715/1315) at Minyat Babīj (al-Zāhiryya/al-Dāhiryya)

The Alexandria canal's height in channel was then used to calculate volumetric flow through the Alexandria canal. Height in channel for the Alexandria canal was then recalculated from volumetric flow via a curvilinear regression solution for the height-in-channel (y-data) of the Alexandria canal given volumetric flow (x-data) for the Alexandria canal. The purpose of the regression was to allow for the calculation of falling height in channel as village feeder canal demand (volumetric flow from village canals) was subtracted from the volumetric flow through the Alexandria canal. Thus given the data from the equation, Vf = $(W_C)\frac{1}{n}(S_O)^{\frac{1}{2}}(\frac{H_C W_C}{2H_C + W_C})^{\frac{2}{3}}$ the values for Vf are taken as the x-data and the values for Hc the y-data, for which the the following regression equation is obtained: Hc = f (V_f) = $(4.5E - 4 \cdot V_f^3) - (2.6E - 2 \cdot V_f^2) + (.65 \cdot V_f) + (.40)$. The regression was continuously recalculated, responding to variations in the parameters values in the **Tables 2 and 3** below. Continuous recalculation of the regression was employed so that any changes in the parameters of the Alexandria canal (W_c, S_o n *etc.*)would reset the coefficients of the equation Hc = f (V_f).

This solution was the then used in iterations to calculate the water velocity and volumetric flow of the village feeder canals. The steps are shown below, first with the Alexandria canal providing water to the first village near the mouth of the canal (Maḥallat Bitūk) at its joining with the Rashīd (Rosetta) branch of the Nile. The quantitative interaction served as the input for the tables below that, shown in sequence. These tables contained the hydraulic parameters of each of the 76 village feeder canals. There were 76 separate tables in total that were used to calculate falling velocity in each of the 76 village

	Sultani Canal		Village Canal (1)			
	Alexandria Canal		Maḥallat Bitūk			
				ROTATE ON	14-Aug	15_Misrā ([illegible]) Mesori (Mesori)
				ROTATE OFF	3-Sep	5_Al-Nasī ([illegible]) Pi Kogi Enavot
Date in Flood Season	Volumetric Flow Alexandria Canal (m^3/s)	Alexandria Canal Depth (m)	Water Velocity in Village Canal (m/s)	Conditional Clause for Volume Irrigated (m^3)	Conditional Clause Rotation on/off	Volumetric Flow in Village Canal (m^3/s)
1-Jun	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30-Jun	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1-Jul	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
31-Jul	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1-Aug	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14-Aug	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15-Aug	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 2. Estimated basin volume and equations for single villages (Alexandria canal)

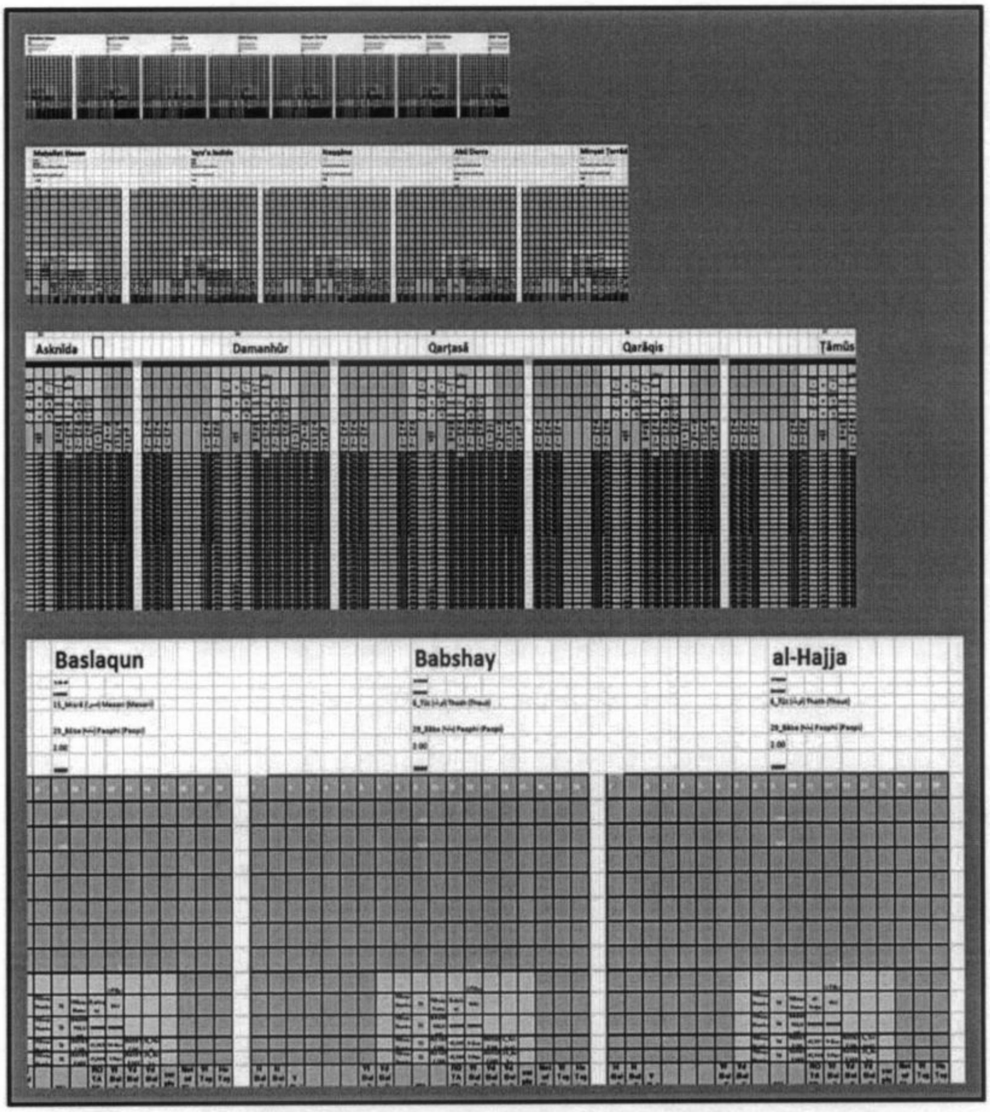


Table 3. Data and equations for multiple villages (Alexandria canal)

feeder canals, i.e. one "module" (shown below) for each of the villages noted in the Qanūn al-Riyy for the Alexandria canal.

Thus the tables for the village irrigation system converted the Alexandria canal's height in channel to the depths of the village system canal. The depths of the village feeder canals were used to calculate the falling water velocity and volumetric flow in each of the 76 village feeder canals (the modules with village names in the illustration above). Every one of the village modules in the computer program repeatedly calculated its y-variables for each day in the interval from 1 June to 5 January (some seven months of the transition from low water to full recession). Each village module received parameter and timing input from the master table which contained the instructions from the Qanūn al-Riyy. These timing parameters were thus the specific Coptic solar days for canal openings and closings, dates specified in the two texts of Ibn Mammātī and that of al-Makhzūmī. The timing parameters were therefore the key controlling instructions for the quantitative simulation as set down some thousand years ago. They were thus entered as commands into this computer model's recreation of the hydraulic solution to a key flow dilemma.

As a crucial step of testing the model the simulation was replicated in two versions, one using village dam rotations and the other version in which the dams were simply left open for the duration of Buḥayra's flood interval, which was 15 Misrā/14 August (in the Gregorian proleptic [tropical] of the early eleventh century CE) to 29 Tūt/2 October. The two variations, rotation and non-rotation, served as the test comparison for the Qanūn al-Riyy version. For the version with rotation, the 76 instructions for the timing of the rotation – as given in the Qanūn al-Riyy - were entered into the program.

Village Name	Basin	Open Dam	Close Dam	Coptic Date Open Dam	Coptic Date Close Dam
Maḥallat Bitūk	[illegible]	14-Aug	3-Sep	15_Misrā (مسرا) Mesori (Mesori)	5_Al-Nasī (نسي) Pi Kogi Enavot
Ūrīn	[illegible]	14-Aug	3-Sep	15_Misrā (مسرا) Mesori (Mesori)	5_Al-Nasī (نسي) Pi Kogi Enavot
Maḥlaat Farnawā	[illegible]	14-Aug	3-Sep	15_Misrā (مسرا) Mesori (Mesori)	5_Al-Nasī (نسي) Pi Kogi Enavot
Maḥallat Ḥasan	[illegible]	14-Aug	3-Sep	15_Misrā (مسرا) Mesori (Mesori)	5_Al-Nasī (نسي) Pi Kogi Enavot
Iqra'a Jadida	[illegible]	19-Aug	8-Sep	20_Misrā (مسرا) Mesori (Mesori)	5_Tūt (توت) Thoth (Thout)
Naqqāna	[illegible]	8-Sep	19-Sep	5_Tūt (توت) Thoth (Thout)	16_Tūt (توت) Thoth (Thout)
Abū Durra	[illegible]	8-Sep	19-Sep	5_Tūt (توت) Thoth (Thout)	16_Tūt (توت) Thoth (Thout)
Minyat Ṭarrād	[illegible]	14-Aug	3-Sep	15_Misrā (مسرا) Mesori (Mesori)	5_Al-Nasī (نسي) Pi Kogi Enavot
Maḥallat Naṣr/Maḥa	[illegible]	14-Aug	3-Sep	15_Misrā (مسرا) Mesori (Mesori)	5_Al-Nasī (نسي) Pi Kogi Enavot
Abū Kharāsha	[illegible]	8-Sep	19-Sep	5_Tūt (توت) Thoth (Thout)	16_Tūt (توت) Thoth (Thout)
Abū Yaḥyā	[illegible]	14-Aug	3-Sep	15_Misrā (مسرا) Mesori (Mesori)	5_Al-Nasī (نسي) Pi Kogi Enavot
Abu Shirak	[illegible]	28-Aug	8-Sep	29_Misrā (مسرا) Mesori (Mesori)	5_Tūt (توت) Thoth (Thout)
Abū al-Siḥmā	[illegible]	14-Aug	3-Sep	15_Misrā (مسرا) Mesori (Mesori)	5_Al-Nasī (نسي) Pi Kogi Enavot
Quhuqiyya	[illegible]	14-Aug	3-Sep	15_Misrā (مسرا) Mesori (Mesori)	5_Al-Nasī (نسي) Pi Kogi Enavot
Minyat Himad	[illegible]	21-Sep	29-Sep	18_Tūt (توت) Thoth (Thout)	26_Tūt (توت) Thoth (Thout)
Mahallat Maryiy	[illegible]	21-Sep	29-Sep	18_Tūt (توت) Thoth (Thout)	26_Tūt (توت) Thoth (Thout)
Sumukhrat	[illegible]	21-Sep	29-Sep	18_Tūt (توت) Thoth (Thout)	26_Tūt (توت) Thoth (Thout)

Table 4. Simulation table applying the rotational system of the Qanūn al-Riyy

The simulation thus traced out the steps by which water velocity in village canal systems decreased as the Alexandria canal's height in channel dropped. The village irrigation system modules calculated water velocity and volumetric flow in village feeder canals for each step of falling height in channel and for each day in the flood season. A data sheet then recorded these falling water velocities and the corresponding saturation ratio (percent of flood basin filled to a height of 1.5 to 2 meters) for each village module.

From the outcome data sheet, 3D graphs of village system feeder canal depths can be seen here, whereby the z-axis represented the height in channel for each of the 76 villages, the y-axis (depth axis) the specific villages and the x-axis the dates in the Nile flood season from June 1 to January 5 (with Coptic dates). The profile for the Nile flood itself can be seen in the curve of the z--axis along the x-axis for time (days). The first of the two 3D graphs (**Figure 22a**) depicts the simulation results for the scenario in which village dams are left open for the duration of the province's flood season. (14 August to 2 October for Buḥayra, see details following.) As can be seen, there is a smooth pattern of falling heights in channel for the villages along the Alexandria canal. The second 3D graph (**Figure 22b**) shows the result of the Qanūn's rotation system. The shuffled pattern of falling heights in channel is the product of the Qanūn al-Riyy's water demand rotation system.

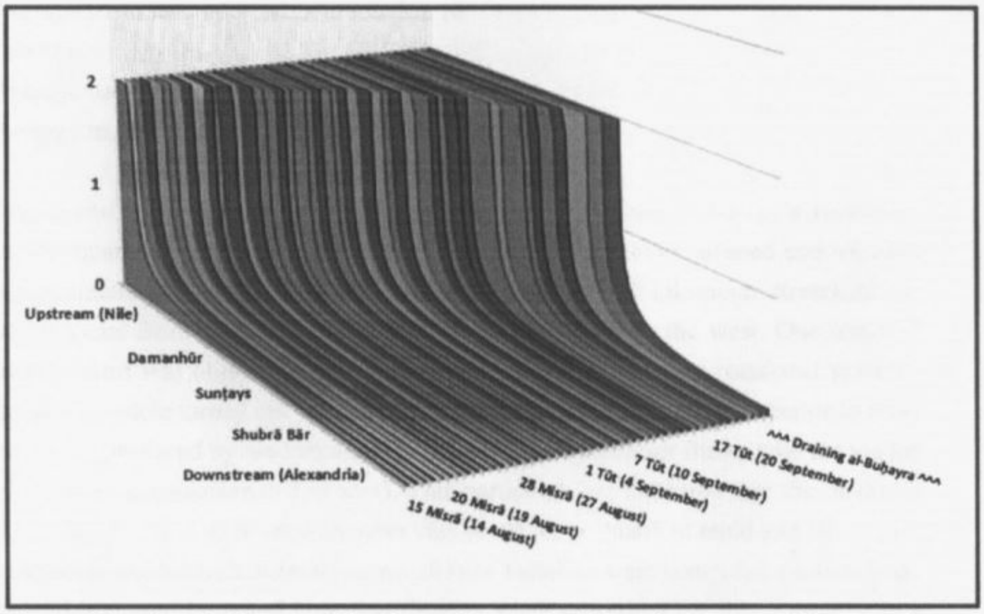


Figure 22a. The 76 villages of the Alexandria canal without the Qanūn; without rotation

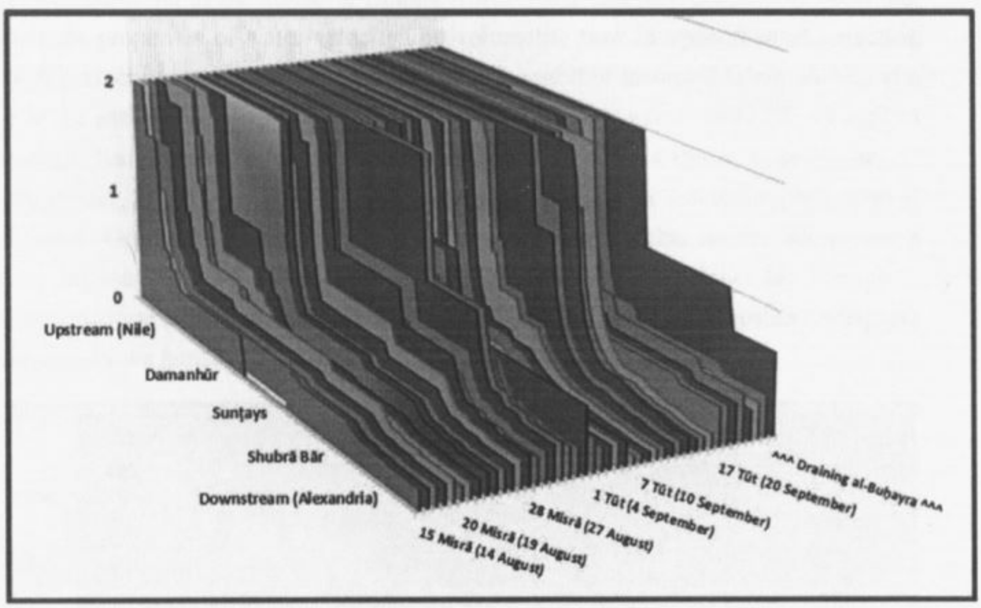


Figure 22b. The 76 villages of the Alexandria canal with the Qanūn; with rotation

Finally, average saturation ratios for all the villages are calculated for both the rotational (Qanūn al-Riyy) and non-rotational (open dam) scenario. The results that favor the Qanun's solution to the dilemma of falling water velocity are shown below, and one can see that the average saturation ratio for the rotational schedule of the Qanūn was twice that of the non-rotating open-dam scheme.

Test (1)

Average basin saturation with rotation 40

Average basin saturation without rotation 21

Test (2)

Average basin saturation with rotation 36

Average basin saturation without rotation 18

Test (3)

Average basin saturation with rotation 57

Average basin saturation without rotation 28

The quantitative simulation results indicated that the Qanūn al-Riyy's rotational system was quantitatively and practically refined. It was apparently attuned and adjusted to the parameters of the village feeder systems along the 120 kilometer stretch of the Alexandria canal from Minyat Babīj in the east to Alexandria in the west. One result of particular interest was obtained by running multiple trials of different rotational systems: the Qanūn's schedule turned out to be the best timing system for rotation, superior to other rotation orders produced by random number generators (or parameter fitting with the via the minimization of least-square differences). This particular fact indicated that the medieval Qanūn's hydraulic rules were set with more than just rules of thumb in mind and this in turn opens the door to a plausible scenario in which flow variables were computed via formulas.

Indeed it should be noted here that there is some precedent for this approach in a general sense, in so far as the medieval Islamic world was at this time producing works that quantified the properties of water velocity and volumetric flow in open-channel irrigation systems. A perfect example of such achievement in the orbit of medieval Islam, though at a remove to the east, is Al-Karājī's work (*Inbāt al-miyā' al-khafiyya*), c. 1000 CE, of applied mathematics. Karaji's mathematical treatise hydraulic quantified the flow properties of irrigation canals, dealing in specific terms with the challenges of calculating the optimal ground slopes. Ground slopes had to be set at very precise levels that set irrigation water's velocity at an ideal mean velocity between the extremes at either end, i.e. fast enough to minimize deposition (silting the channel) and yet slow enough to forestall erosion (collapsing the channel), shown here in its modern formulation as the Hjulström curve:

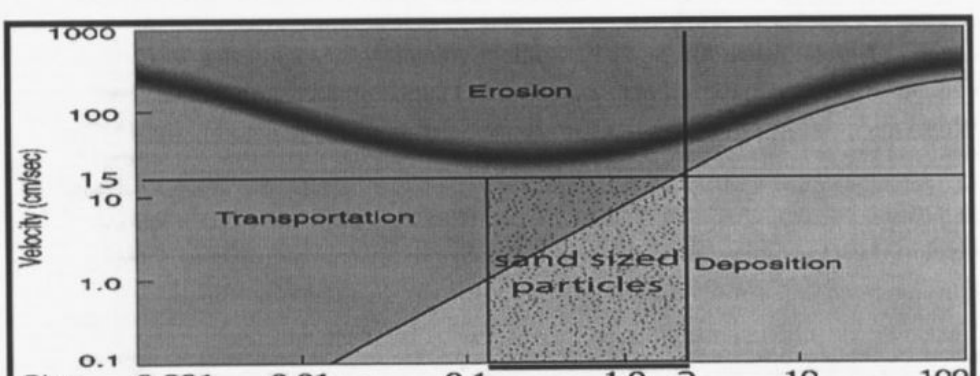


Figure 23. A Modern equivalent?
The Hjulström curve for deposition, erosion and transportation (Given water velocity and grain size)

While we lack the material evidence for the mathematization of the Qanūn's dictates, it wouldn't be surprising to find such an approach, as Ibn Mammātī's surviving treatise that records the Qanūn al-Riyy also discusses the practical quantitative solution of measurement problems via the use of trigonometry. It was by no means beyond the prowess of medieval Islamic civilization to produce practical applications of sophisticated mathematic problems like this one. The Islamic interval, the Islamic millennium in Egypt, did indeed have a codified law for hydraulic operation and hydraulic flow. To the contrary of the invective of nineteenth century Europe – and indeed the widely held view in the scholarly community today, Egypt's irrigation system in the Islamic era was a complex system and was the subject of applied hydraulic solutions and formal rules. The Qanūn al-Riyy was the blueprint and it had the force of law. It was a central facet of medieval Egypt's history, however it was eventually transformed.

Ⅳ. The Qanūn al-Riyy Text

(Text of al-Makhzūmī from Khiṭaṭ 1: 169-171)

وقال أبو الحسن المخزومي في كتاب المنهاج: أمّا خليج الإسكندرية فإنه من فوهة الخليج إلى ترعة بودرة ليس على شيء منها سدّ بمخرج محلة تبوك اسينة أورين محلة، فرنو محلة، حسن منية طراد، وتعرف بالقاعة محلتا نصر ومسروق، فأمّا ترعة لقانة فإنها تفتح بعد سبعة أيام من توت، والترعة الجديدة تفتح في السادس عشر من توت، وترعة بودرة تفتح بعد سبعة أيام من توت، وترعة بو يحيى، وترعة بو السحما، وترعة القهوقية ليس على شيء من ذلك سدّ، وترعة الشراك تفتح بعد سبعة أيام من توت، وترعة بو خراشة، وترعة البربيط يشرب منها ديسو وسمخراط، وشيرنوبة، ومنية حماد، وسنادة، وبعض محلة مارية، وترعة فيشة بلخا تفتح في ثاني عشر توت، وجرت العادة أن تفتح في النوروز. ترعة بويط، ومقطع سمديسة يفتح في الثاني والعشرين من توت، ومقطع باطس يفتح في تاسع عشر توت، ولما سدّ المقطع المذكور عملت بعد ذلك ترعة تروي الصفقة القبلية منها، فتفتح في يوم النوروز. ولما استحدثت ترعة أفلاقة، وخرجت في أرض باطس جرت العادة إذا رويت الصفقة القبلية من أفلاقة، تطلق الترعة المذكورة على القسم البحريّ من باطس إلى أن يروي، وترعة القارورة محدثة، وترعة بفوها تفتح في ثاني عشر توت، وترعة الفلاقة تفتح في عاشر توت. وترعة اسكنيدة تفتح في سادس توت.

تراع بحر دمنهور تفتح في العشرين من مسري إلى سادس توت، ويروى منها بعض طاموس، وبعض كنيسة الغيط، وبعض قرطسا ودمنهور، ترعة القواديس منها تشرب شيرا النخلة، وكوم التلول، وتراع شيرا النخلة تفتح على أعاليها من أوّل توت، وترعة بسطري تفتح في خامس عشر مسري، وترعة مسيد تفتح في ثامن توت، وترعة سنتوية تفتح في ثامن عشر توت، وبحر دمشوية يفتح في العشرين من مسري، ومنه تشرب منية رزقون وسفط كرداسة ودمشوية ومحلة الشيخ ومصيل، وترعة دمشوية تفتح في تاسع توت ويقيم الماء عليها سبعة عشر يوما، وتفتح إلى محلة الشيخ ومصيل يقيم الماء عليها ثلاثين يوما، ويسدّ بعد ذلك على دمشوية سبعة أيام، وعلى سفط ومنية رزقون، ترعة برسيق كانت تفتح في أوّل توت.

محلة برسيق: ليس عليها سدّ.

محلة الكروم تفتح في ثامن توت ومنها تشرب عدّة أماكن وهي محلة الكروم وكفورها، وهي دنيسة، وكوم الولائد وكوم الصخرة وديرامس والصفاصف، وما يخرج عن كفورها، وهي تلمسان والجلمون من حقوق محلة كيل، ومنها تشرب الجهة الغربية.

شيرابار ليس عليها سدّ وترعة قافلة كانت تفتح في ثامن توت، وليس عليها الآن سدّ، وترعة بلقطر وكفورها كانت تفتح في تاسع توت، وليس عليها الآن سدّ.

ترعة الراهب ليس عليها سدّ، وترعة دسونس المقاريضي تسقي الحلفاية وتفتح في ثامن توت، وكذلك ترعة مرحنا والملعقية، وترعة نيلامة، وبيشاي، وآخر تراع الحجيجة، وترعة الكريون تفتح في ثامن توت، وترعة السلقون كانت تفتح في سادس توت، وليس عليها الآن سدّ، وترعة أرمياخ تفتح في ثاني عشر توت، وترعة ابلوق تفتح في سادس توت، وأمّا جون رمسيس، فإنّ بحر رمسيس كان يضرب السدّ فيه على تراع رمسيس من أوّل النيل إلى سابع عشر توت، والذي يشرب من السدّ المذكور من النواحي والكفور رمسيس ومحلة جعفر وفليشان، وبعض أبنية البعيديّ، وبعض خربتا وبعض البلكوس، وبعض بولين وبعض محلة وافد والبيضاء، وبعض طيلاس، ثم يفتح سدّ دكدولة، وهو محدث يقيم الماء عليه عشرة أيام، وتشرب منه دكدولة، ومحلة معن ومنية أسامي وبعض صيفية، ثم يقطع سدّ القطامي وهو محدث، ومنه يشرب بعض جنبوية وبليانة البحرية والسرّة وأبو حمار والبهوط، ثم يقطع سدّ رسونس، وأبو دينار وترعة طيرينة، فيشرب منه دنسال وطلموس يقيم الماء عليها ستة أيام، ومنه تشرب منية عطية وسلطيس.

وأما

بحر دمنهور فإنه يسدّ على سلطيس إلى سابع عشر توت، ومنه تشرب سلطيس وزهرا وبعض طابوس وبعض قرطسا وبعض كنيسة الغيط ودمنهور، ثم يقطع سدّ ندبية وهو محدث فيقيم ثمانية أيام ومنه تشرب ندبية ودقرس والعميرية والنسرين، ثم يفتح ويسدّ على محلة خفض، ومحلة كيل ومحلة نمير، ثم يقطع سدّ سلطيس، وهو محدث فيقيم عشرة أيام بعد اختلاط الماءين ببحر دمنهور، ورمسيس، ثم يقطع جسر ملولة ومنه تشرب تروجة وأرسيس والمراسي وغابة الأعساس وبعض سمرو، ومحلة نمير، ويبقى هناك إلى انقضاء النيل.

وأمّا

ترعة طيرينة فهي محدثة وإذا رويت طيرينة تطلق على دسونس أمّ دينار، ثم تقطع على طاموس بمقدار ريّها ثم تطلق في النيل العالي على أرض قراقس ويطلق الماء على قرطسا وكنيسة الغيط وخليج الطيرينة إذا خرج الماء منه يسقى منه في أوّل النيل إلى أن يضرب جسر شيراوسيم، فيسقي منه شيراوسيم، وبعض البلكوس، وحفيرة الزعفراني، وبعض بولين، ومسجد غانم والصوّاف وكوم شريك ومنية مغيين، وتل القطامي ومحلة وافد، ثم يقطع جسر دليجة، ومنه يشرب بعض خربتا، وبعض فليشان وبعض بولين والبيضاء، ودنست وتلبانة الأبراج، وتل بقا والحذين واليهودية، والنسوم، وأبو صمادة والحصن وقلاوة بني عبيد وطوخ دخابة ودرشا وسقرا ودليجة ونخة وطية، ثم يقطع على منية وزراقة الحجر والمخزون وبعض حيارس والفزيم وأبو سمار وأمّ الضروع.

خليج ابن زلوم ويعرف بخليج ابن ظلوم، وسدّ مخرج التعيدي لا يفتح إلى عشرة أيام من توت، ومنه يشرب شابور وكنيسة مبارك وبعض سرسيقة وبعض دموشة ومنية يزيد

وحوض الماصلي وحصة سلمون وبعض سنيت وبعض التعيدي وبعض فليشان، ثم يفتح فيشرب منه أمليط وبعض اناي وبعض كنيسة عبد الملك وبعض أرمنية وميسنا
وبعض محلة عبيد وسفط خالد وبرنامة وشبرانوبة وكيمان شراس، وبعض دمشوه وتقام الحرّاس على جسر سفط

V. Enforcement Mechanisms

Surveillance during flood time was the executive power that enforced the system of water demand rotation.[16] The scale and scope of long canal control meant coercion: the solution most readily available. Coercion came via the provincial governor and his staff. (Sometimes as the annual inspector, kāshif al-jusūr, and his staff). Mechansims for system control meants that the governor's staff consisted of a bureaucracy that was at least in part devoted to irrigation. There were engineers (muhandis/muhandisūn) and provincial irrigation experts (khawlī'/khawlā). The muhandis practiced a set of skills that had been tailored over the Islamic centuries to hydraulic matters.

The rest of the governor's staff consisted of what was more or less the standard fare for both bureaucracies (e.g. the kātib, the scribe) and their enforcement mechanisms (ḥāris, guard).[17] The fifteenth century al-Maqrīzī's *(al-Sulūk* I: 61) notes the role of the watchmen/ guard (the ḥāris) who was to be found stationed at many points in the irrigation network. His role involved carefully monitoring the irrigation system at flood time, watching for any breaches in the dikes or ruptures in the canals. Another such type, the khafīrs, were under the control of the provincial governor (wālī).[18] Their function was also to stand watch on the (sultani) dikes, looking for any leaks or ruptures. Furthermore, their jobe also involved policing the dikes for misuse of water.[19] This was to ensure order and to see to it that villages did not fill their basins until the time specified by the schedule in the Qanūn al-Riyy.[20]

That this executive machinery was responsible for enforcing the Qanūn al-Riyy's regime, rotational order and all, is spelled out in memoranda and passages from the medieval Arabic chronicles that address the duties of the governor (the wālī). A memorandum from the mid-1200s (Kitbugha: (from the same Sulṭān, Qalāwūn), for the

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[16] Surveillance at flood time was of key importance. M. M. A. Abū Zayd, *Al-Nīl Wa-Miṣr: Dirāsah Li-Athar Al-Nīl Fī Al-Ḥayāh Al-Iqtiṣādīyah Wa-Al-Ijtimā'īyah Fī Miṣr Min Al-Fatḥ Al-Islāmī Ḥattá Muntaṣaf Al-Qarn Al-Rābi' Al-Hijri¯* (Cairo: Dār al-Hidāyah, 1987), 13. The fact that amirs were commonly assigned to dikes in flood time is also an indication of just how dire and desperate this need could be. See Sato, op.cit., 112.

[17] Sato, op. cit., 127-145 describes the staff of the provincial governor.

[18] See also the roles of the khufarā' and ḥurrās in Cooper, 1973, 229; Sato, op.cit., 233; Abū Zayd, op.cit., 13.

[19] Sato also notes (233): "in order to maintain order in the village community, a watchman (khafīr, ḥāris), who would be given rizaq for his work, was hired to watch the canals." Sato, op. cit. cites Ibn Mammātī, op.cit., 229, 305-306. Dike watchmen themselves had more of a timeless quality: Nicolas Michel, "Travaux aux digues dans la vallée du Nil aux époques papyrologique et ottomane: une comparaison," *Cahier de Recherches de l'Institut de Papyrologie et d'Egyptologie de Lille*, 25, 2005, 261. Nicolas Michel notes the timelessness of this function, as he traces the notion of dike watchmen back to Ptolemaic Egypt (where they are listed in Greek as chômatophylakes).

[20] See the discussion of the Tadhkira to Amir Kitbugha in Sato, op.cit., 117; al-Makzūmī's detailed operations instructions of the Qanūn al-Riyy for the province of al-Buḥayra uses the alternate word, ḥarrās, for these (sultani) watchmen and gives specific instructions for guards to be on watch at the dike of Safṭ Khālid. For al-Makhzūmī text from al-Minhāj, see al-Maqrīzī, op.cit., 1: 171. See also the alternate text from Ibn Mammātī, op.cit., 229.

year 1281 CE) mandates that the governor be personally involved in preparing dikes for the flood, and that he is not to delegate the matter to an agent.[21] Furthermore, it stipulates that the governor is to be accountable for any defects in the irrigation system at flood time.[22] Another morandum[23] mandates that the governor must witness the openings of dikes, dams, and weirs during the Nile flood. His personal authority and even his physical presence are required, and this in the context of the Qanūn's imperatives for flood control.[24] (إقاف منه بحضور اكابر البلاد و مشائخها و خولتها و الاشهاد عليهم و لا يكسر جسر الّا بأمر الوالى فى تلك الجهة و) In this context, the same memorandum mandates that the proper times for opening and closing irrigation devices are to be followed at flood time (i.e. the orders of the Qanūn al-Riyy).[25] (من غيرها و الشهادة على الخولة و المهندسين بذلك لا يفتح قنطرة و لا يكسّر ترعة الا عند استحقاقها و في وقتها على حكم مصلحة الوقت و مقدار النيل و كثرته).[26] Other attestations to the role of the provincial governor include examples such as a decree issued to the wālīs of Upper Egypt to "bring an

[21] See Tsugitaka Sato, "A Memorandum to Amir Kitbugha" in idem, *State and Rural Society in Medieval Islam*, 111-112. "He (Amir Kitbugha, the Na'ib al-Sultana) is to assure that the governors (wali) act themselves, and not to entrust work to representatives (mushidd)."

[22] Alex Moberg, "Regierungspromemoria eines Agyptischen Sultans," *Festschrift Eduard Sachau, zum siebzigsten Geburtstage gewidmet von Freunden und Schülern*, ed. Gotthold Weil (Berlin : G. Reimer, 1915), 413, Faṣl 8 and the source of transmission is attributed to Abdullah ibn Abd al-Ẓāhir.

[23] Qalāwūn's son, al-Malik al-Ṣāliḥ 'Alī was nominally in charge of affairs while Qalāwūn was away. The memorandum (takhkira) to Amir Kitbughā is superbly analyzed by Sato, op.cit., Chapter Five: "A Memorandum to Amir Kitbughā," 105-123.

[24] Northrup, op.cit., 260 based on the takhkira to Qalāwūn's son, al-Malik al-Ṣāliḥ addresses the issue of "Regulation of Flow and Equitable Distribution of Water. The second major concern was the equitable distribution of water and regulation of its flow. This required that the irrigation schedule, inseperably linked to the Nile flood cycle, be strictly observed. According to one of the memoranda addressed to al-Ṣāliḥ, he was to issue orders that no canal was to be opened or dike broken until the Nile had reached its heighest level and the supervisoers, and land surveyors had given their testimony in that regard. Al-Ṣāliḥ was also directed to warn the walīs and nā'ibs in case the deputy of an amir or anyone else broke a dike, thereby benefitting his master but resulting in the desication of the remaining land. No dike was to be broken except by the order of the wālī of that place in the presence of the notables, headmen, and supervisors of the country." And Northrup (p. 260) continues: "In another section of the same document the onus for ensuring that water was distributed fairly was placed on the walīs. Al-Ṣālīh was instructed to caution the walīs lest anyone complain about them because their master's iqṭā's had become desiccated as a consequence of negligence on their part, because of an excessively low water level, for favoring one area over another, or because of the domination of a weak individual by a storong one, or of a regular soldier by an amir. All were to be treated impartially." Finally, Northrup (p. 260) says " That the concern for equitable irrigation was linked to the matter of productivity and revenues indicated in another of al-Ṣāliḥ's memoranda. Therein he was advised to enforce strictly the matter or inspecting the dikes and distributing the water on an equitable basis, both to avoid disputes and to complete the collection of diwānī taxes on schedule." See also Alex Moberg, op.cit.

[25] According to 'Āmr Nagīb Mūsā Nāṣir, *Al-Ḥayyāt Al-Iqtiṣādiyya Fī Miṣr* (Cairo: Dār al-Shurūq, 2003), 171, the each step in the implementation of the Qanūn al-Riyy was documented in writing. And where provincial governors are expressly commanded to follow the exact instructions of the Qawānīn al-Riyy:(... يتقدم الولد الى الولاة بالاجتهاد في ريّ البلاد وتحذّرهم من ان يبور منها قعر قصبة او ان تهمل امورقوانين الريّ) and not to ignore any aspects (tuhmala 'amūr qawānīn al-riyy) of these instructions.

[26] Alex Moberg, op. cit.,

فصل و اذا اتمّ الله نعمته اسبغ رحمته بزيادة النيل
المبارك و عموم رحمته و شمول بركته يلاحظ الولد امور الجسور و التراع و يكتب الى الولاة بحفظها و ضبطها و مبيت الرجال عليها و تحصيل الاصناف بحيث لا يختلّ جسر الا و تكون الاصناف و الالات التى تدعى الحاجة اليها حاصلة لا عائقة لها خصوصا جسور الجيزة فإنّ امر مهمّ لا ينبغى الغفلة عنه طرفة عين و يرتب الحمام الرسائلى عند مباشرتها لاحتمال ان يتجدّد فيها خلل فيستدرك سريعا بأمير كبير يسيّره للوقوف على ذلك و تلافيه و تداركه و يجعل هذا الامر نصب عينيه يتقدّم بأن لا يفتح جسر و ينفّس عيه و لا يفتح قنطرة و لا يكسّر ترعة الا عند استحقاقها و في وقتها على حكم مصلحة الوقت و مقدار النيل و كثرته من غيرها و الشهادة على الخولة و المهندسين بذلك يحذر الولاة و النوّاب من انّ احدا من نائب امير او غيره يكسر جسرا بيده لمصلحة اقطاع مخدومه تشريق ما عداها و لا يكسر جسر الّا بأمر الوالى في تلك الجهة و إقاف منه بحضور اكابر البلاد و مشائخها و خولتها و الاشهاد عليهم. فصل يتقدم الولد الى الولاة بالاجتهاد في ريّ البلاد و تحذّرهم من ان يبور منها قعر قصبة او ان تهمل امور قوانين الريّ و نظمها و إنفاظها و يحذّر الولاة من ان يحضر احد شاكيا منهم بسبب تشريق اقطاع مخدومه لاهمال او تفريط او محاباة جهة دون جهة او تغلب قوى على ضعيف او امير على جندىّ و تكون المساواة شاملة و المعونة تامّة.

end to struggles over water." The decree states that the governors are to, "notify peasants (fellāḥūn) that each village shall have irrigation rights for a set of days (and) see to it that all violaters are punished.[27]

Second to the provincial governor was the annual dike Inspector, Kāshif al-Jusūr, who played a role similar to that of the governor but it is not entirely clear how the overlap between the two was spelled out in practice. As to some more specifics about these kāshifs; it seems that they were just as intimately involved with dam (sadd) openings (fataḥa) and dike (jisr) openings (qaṭa'a) as the provincial governor was. They also employed guards (ḥirās) atop the dikes during flood time.[28] It should be noted that the kāshifs of the jusūr, perhaps some 20 or so in number, were true tokens of centralization, as the medieval irrigation system was centralized – at least in part. But it looks as though the kāshif's connection with the center may have been more than just a tight chain of authority; the kāshif had the same kind of mandate for watching, directing, and personally supervising the operation of irrigation components like the dams (sadd, sudūd) which connected the sultani system to the baladi networks and the dikes (jisr/jusūr) that contained the large-scale basin enclosures.[29]

Afterword: Rotation Applied Across the Delta

Beyond the dynamic of sultani canals like the Alexandria canal and village irrigation systems lay a larger scale and higher-stakes hydraulic issue: the interaction of the Nile river with the numerous sultani canal systems throughout Egypt. Here again one can see the same type of hydraulic risks and once again a solution proferred by the Qanūn al-Riyy. The Qanūn was not only directed at the problem of canal usage between irrigation systems (sultani-baladi, baladi-baladi) but also between the irrigation system and the Nile.[30] Examining this hydraulic dilemma on the scale of the Nile river suggests that we use a quantitative model for the Nile flood – in addition to an application of the method used above for the sultani canal to village system dynamic. This discussion is therefore broken into two parts: section (1) Nile flood profile analysis and section (2) modeling the dynamic of Nile to Sulṭanī canals.

Section (1) Nile Flood Profile Analysis

The model presented here is part of an ongoing project that studies the profiles of Nile floods. The profiles are the daily readings for the height and volumetric flow of the Nile from the beginning of the flood season in June to the end of the flood season in November/

[27] Sato, op.cit., 224 and see al-Qalqashandī, op.cit., 11: 436-437.

[28] Such guards were apparently serious business; a European traveler noted that armed horsemen accompanied these watchmen atop the dikes. See Majdī al-Rashīd Baḥr, op.cit., 179. These were deemed necessary to guard against breakage, accidental or deliberate. See Abū Zayd, op.cit., 13.

[29] See Abū Zayd, op.cit., 62-4 and Al-Ẓāhirī, op.cit., 129.

[30] This subject has been explored before, in discussions of irrigation system decay following the Black Death (Stuart J. Borsch, "Nile floods and the irrigation system in fifteenth-century Egypt," *Mamluk Studies Review* 4, 2000, 131-145; idem, *Black Death in Egypt and England*, Austin, Texas: UT Press, 2005). but here we will analyze the relationship between this quantitative interaction (Nile-irrigation system) and the written Qanūn al-Riyy.

December.[31] Flood profiles tell us how much water was being discharged on any given day and thus whether the flood was normal/moderate flood (a good flood) or an extreme flood (a bad flood – one that was too high or too low). The methodology for *Nile Flood Profile Analysis* consists of building profile simulations taken from two directions; the baseline flood curve and the annual data. The baseline flood curve is single profile curve as calculated by the averaging of multiple sets of complete flood readings taken from medieval and modern records. The annual data consists of the partial flood readings for all flood years between 640 CE and 1904 CE. Quantitative modeling consists bringing these two together, the baseline flood curve and the annual data, so that the computer simulation can tease out the likely trajectory of the entire flood curve for every one of these historical floods. Flood profiles can be used to enhance regressions, such as Nile flood maxima and prices shown here in a graph for the late 1300s and the 1400s.

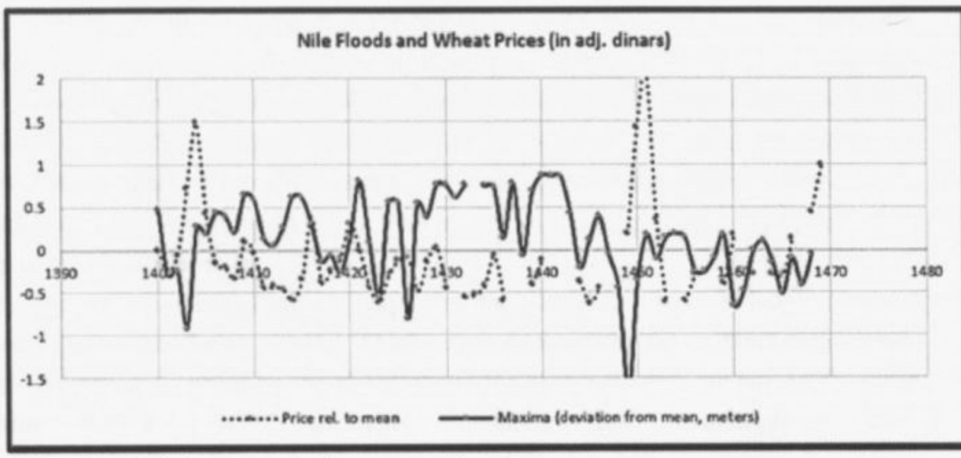


Figure 24. Nile floods and wheat prices (in adj. dinars)

31 The Nile flood records have received a great deal of attention ever since Sāmī Amīn, *Taqwīm al-Nīl* (Cairo: Maktabāt al-Kutub al-Miṣriyya, 1915-36) began collating flood records and Omar Toussoun, *Mémoire sur l'histoire du Nil* (Paris: Imprimerie de l'Institut Français d'Archéologie Orientale, 1925) compiled flood tables – but this record consists only of the flood's low point and high point. William Popper's landmark study, The Cairo Nilometer, corrected Toussoun's tabulations of the flood and explored the Nile records in great detail, but even Popper never did more than dabble with flood rise in a few instances (a study of the rise of the Nile for eight floods scattered over the medieval period). Many scholars, from historians to scientists, have made extensive use of Toussoun's tabulations of the flood high and low, but Nile flood profiles have remained untouched. Analysis of these Nile flood profiles is one part of a collaborative venture (Nile Flood Profile Analysis). In the larger project I am leading a team consisting of myself, two other scholars of medieval Arabic and two computer scientists. This collaborative effort is a long-term project that consists of studying medieval Arabic texts for flood profile data and examining the data via computer simulation: Wan Kamal Mujani (Universiti Kebangsaan, Malaysia), Tarek Sabraa (University of Damascus, Syria) and computer scientists, Zainol Bin Mustafa (Universiti Kebangsaan, Malaysia), Nur Riza Mohd Suradi (Universiti Kebangsaan, Malaysia). The end-goal, an analytical online tool for scholars to use and interact with, will bring with it the results of our analyses of the qualitative aspects of human history and endeavor - and the quantitative aspects of the natural world. The contribution to the humanities promises to be substantial because so much will be learned about the interaction between flood events and Egyptian history – economic, social, intellectual, and environmental history. From the perspective of the hard sciences, the project seeks to fine tune the Nile flood record, which has been used as an instrument to study climate change for the approximately 1,400 years of flood maxima and minima data. With profile data used to fill in the full picture of the flood's trajectory, the actual flood discharge can be read more accurately. Volumetric discharge, not flood minima and maxima, is the real goal of those studying historical climate change, and the project hopes to improve upon the accuracy of the scientific record through the analysis of medieval Arabic narratives. As Egypt's Nile Delta stands so much to lose via the coming years of global warming, the geographical focus of this study is relevant in more than one way.

We use two examples of simulation methods to illustrate how the Nile flood is modeled in this paper: SIM 1 and SIM 2 MOD.

SIM 1

The first trial simulation model that we developed (SIM 1) does not apply annual flood profile data per se. It uses instead uses the data stream of annual flood crests (maxima) employed at present by scholars of Nile floods, historians and climatologists. SIM 1 takes the year's crest height and generates the most likely flood curve one would expect for this crest. It does via the following steps: First, SIM 1 compares the crest for the given year with the height of a mean flood for that year. To do this comparison, SIM 1 calculates the expected build-up of alluvium on the Nile River bed for that year by applying interpolating between Popper's cycles of river bed silt accumulation over the long-term (from the seventh century to the nineteenth century). SIM 1 thus estimates how high the average flood peak would be relative to the fixed point of the Nilometer as the river bed rose in increments, year after year. For an example we use the flood year 1429 CE, for which we estimated silt accumulation from 622 CE to 1429 CE as 1.097 meters. The "average" flood crest estimated for 1429 CE then equals a reading of 18' 20", where 18' 20" means 18 *dhirā'* (ذراع : cubits: forearm spans of some ½ meter) and 20 iṣba' (إصبع :fingers: finger widths of about 2 centimeters each) which works out to 9.63 meters as measured from a zero point at the bottom of the Nilometer pillar.

Second, SIM 1 obtains the crest height for the year 1429. The crest height recorded that year for October 3 was 19' 16". This reading comes from the maxima data stream, the crest heights as recorded by Ibn al-Ḥijāzī and Ibn Taghrī Birdī in the late 1400s, when they made copies of the records kept by the Nilometer guardian. Toussoun provides tables for these readings; Eric Chaney in this case provided the data from a manuscript of Ibn al-Ḥijāzī from the Bibliothèque Nationale. This reading of 19' 16" translates to 10.01 meters as measured from a zero point at the bottom of the Nilometer pillar and SIM 1 compares this 1429 CE flood crest to the average crest above (18' 20" or 9.63m) and calculates that the 1429 CE flood was .38 meters above the estimated mean.

Finally, SIM 1 applies this increment of .38m above the mean to the baseline curves derived from the late nineteenth century, when daily flood heights provided – for the first time - complete flood profiles of daily readings from 30 June to 31 December, as shown for different floods in the 1870s and 1880s in the graphs below (**Figures 25 and 26**).

SIM 1 then uses the baseline curves to find an anticipated flood shape for a crest .38m above the mean and the result is what the user sees on the current read-out of the user-interface. That is to say that when the visitor to the website types in the year 1429, SIM 1 responds with the following read-out in which one can see the juxtaposition of SIM 1, a mean flood, and two other baseline floods (the "lowest" which was the 1877 CE flood – and the "highest" which is an amalgamation of the 1874 and 1878 high floods).

We can see in this simulation an indication that the flood was above the mean – so that .38m above the mean falls well within the range of "good floods" – i.e. those floods neither so low as to cause drought and unirrigated flood basins, nor so high as to cause damage to irrigation infrastructure and human habitation. The flood of 1429 CE would appear to be a

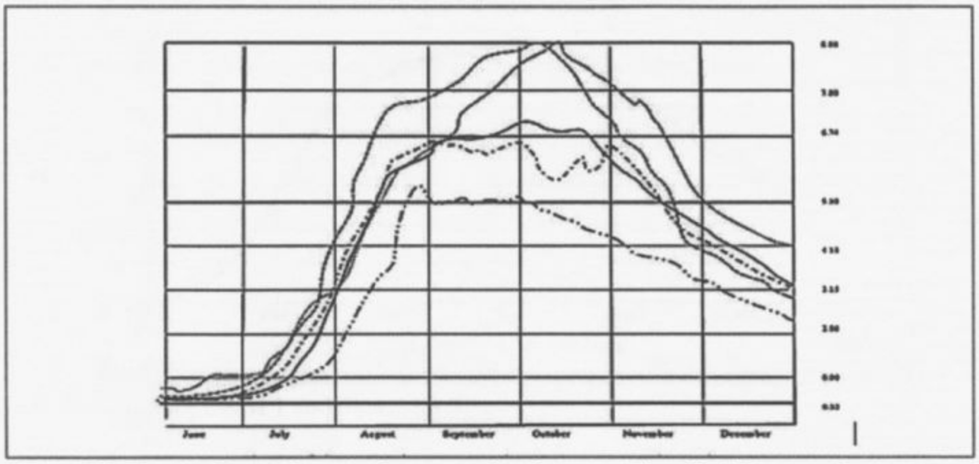


Figure 25. Graph of late Nineteenth century flood curves (Flood height over time, as measured by the Roda Gauge at Cairo)

Source: Willcocks and Craig, *Egyptian Irrigation*, 1913

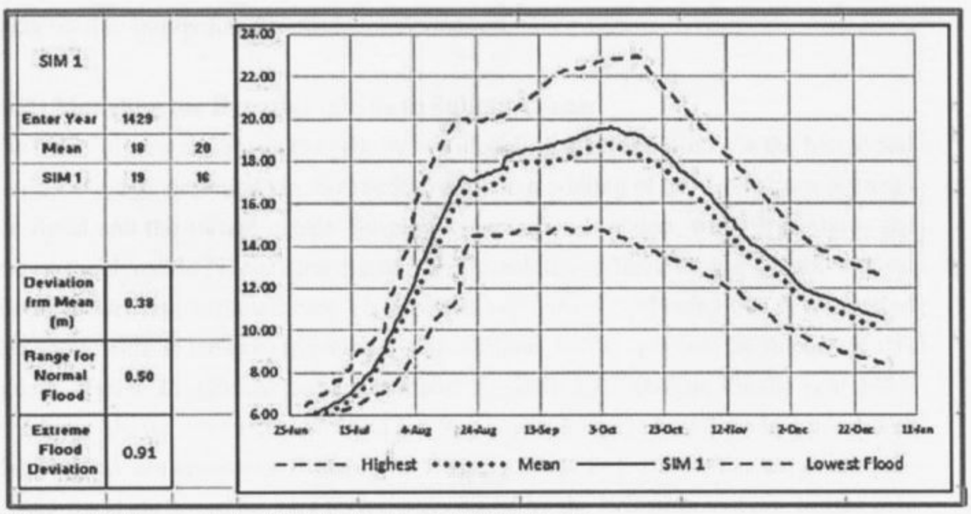


Figure 26. Screenshot of SIM 1 for the 1429 CE flood

good flood, as measured by the crest reading alone.

SIM 2 MOD

SIM 2 MOD is a curve that connects the dots between profile data points, while moderated (MOD) by the baseline curves in order to infer the curves of the lines that the missing flood data might be expected to trace on the graph (**Figure 27**). So this SIM 2 MOD is more or less a quantitative record of the actual flood profile. Using the same flood year, 1429 CE, as the example, SIM 2 MOD takes advantage of all the available flood data for that year and traces out the path of the flood curve. In this read-out example shown below, the actual flood curve composed largely of connected data points (SIM 2 MOD) can be compared with the hypothesized curve (SIM 1) that is based on the flood crest alone. For 1429 CE, there are at present 15 data points given for the flood curve, starting with the flood qāʻ (the qāʻ was the reading on 30 June, or Coptic 27 Baʼūna, the traditional date that they used for a recorded minimum, which was not the real low water).

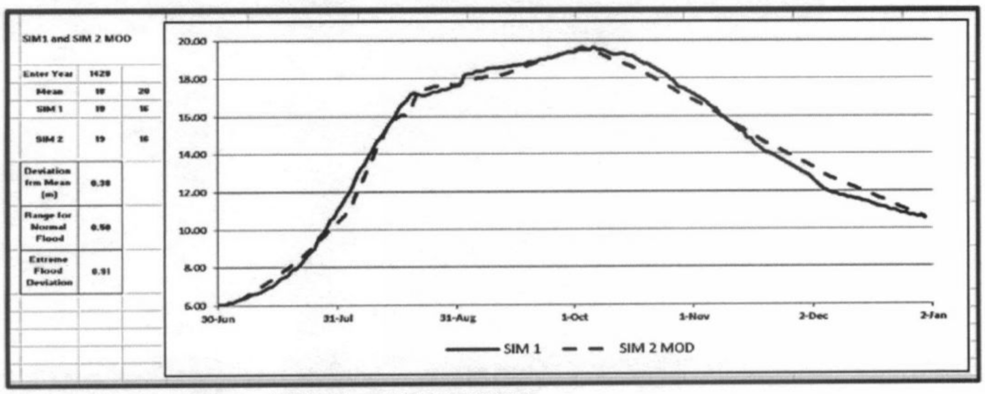


Figure 27. Screenshot of SIM 1 and SIM 2 MOD

What can be seen from the dotted line of SIM 2 MOD is that the actual data fills in a curve that closely approaches that of SIM 1. In this particular case, the two are extremely close. SIM 2 MOD can be thought of as a sort of drafting pad for the data, with baseline curve data used to interpolate for missing information.

Section(2) Modeling the Dynamic of Nile to Sulṭānī Canals

The most important steps in the process are modeling the flood itself via the height and volumetric flow data provided via this method and the modeling of the interaction between the Nile flood and the sultani canals. Turning to the second section, we will examine the dilemma of the dynamic Nile-sultani canals and the solution offered by the Qanūn al-Riyy. The dilemma itself is illustrated here via a case study from the fifteenth century, a period in which there were extensive irrigation system failures that magnified the impact of this dynamic. In **Figure 28**, one can see a schematic of a Nile flood profile, for the year 1461. The schematic shows the truncated flood for that particular year based on historical data from the Mamluk-era chronicler Ibrāḥīm Ibn ʿUmar al-Biqāʿī (d. 1480). The truncated path of the 1461 flood shown in the plot above was caused by the irrigation system. In this case damage to major irrigation channels in the eastern side of the Nile Delta and poor decision making on the part of the Mamluk irrigation authorities - governors, wālī(s) and inspectors, kāshif(s) - led to the opening of an enormous conduit of water by which a substantial portion of that year's volumetric discharge was lost, estimated in the simulation as some one billion cubic meters of floodwater (in excess of one percent of the Nile's average annual 84 billion cubic meter discharge).

Thus problems with the irrigation could have substantial impact on the Nile flood. What is of principal concern for this discussion is the interaction between the two. It is clear that as the Sultani canals had the effect of lowering the level of the Nile, the same type of problem with velocity and height in channel were created. Sultani canal volumetric demand lowered the level of the flood, sultani canal height in channel decreased, ultimately leading to the problem of low water velocity in village feeder canals – hence poor irrigation and a bad harvest. The basic schematic that illustrates this dynamic (**Figure 29**) is similar to the one used above for the Alexandria canal, but here the Nile is shown and the sultani canals example is the Baḥr Abī al-Munajjā of the eastern Delta province of Sharqiyya.

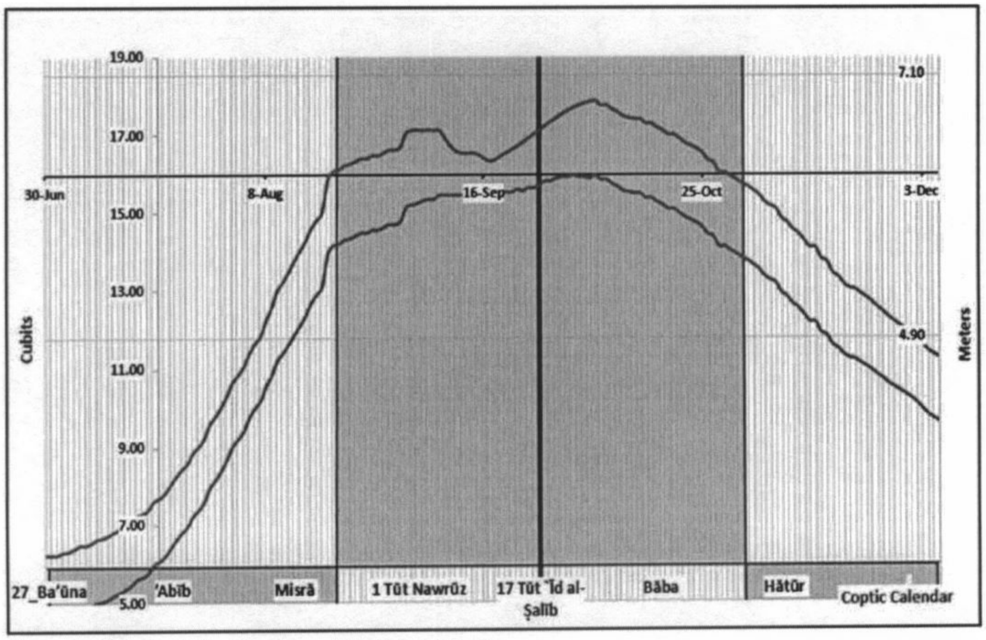


Figure 28. The Nile flood profile for 1461 CE

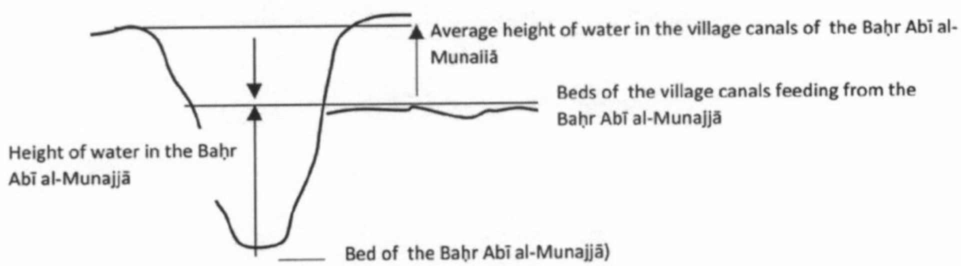


Figure 29. Schematic (Nile and irrigation systems)

The solution offered by the Qanūn was essentially another rendition of the solution used for the Buḥayra province, and that means rotation. In this case, the opening of dams to the sultani canals was rotated with the same purpose of keeping velocity and height in the sultani canals as high as possible. Surviving instructions for the application of the Qanūn al-Riyy's for the interior provinces of Minūfiyya and Gharbiyya are shown in **Table 5**. What can be seen is that the most of the openings of dams, dikes, canals, and zallāqas takes place after the openings for the Buḥayra provinces sultani canals, thus there are turns for different parts of the Delta, taking advantage of both rotation and the full flood season.

Dikes (jusūr) of Shirījah	12 Tūt	15-Sep
The dam (sadd) and spillway dam (zallāqa) of Liyāna Shaṭanūf	17 Tūt	20-Sep
The Umyūṭ and Birṭās dike (jisr)	3 Bābih	5-Oct
Abistū and Quṭbī	5 Bābih	7-Oct
Mudūra bi-Malīj	15 Bābih	7-Oct
Tur'a Bilāya	6 Bābih	8-Oct
Sakhā Dike	8 Bābih	10-Oct
Minṣal Jisr al-Mādarānī	8 Bābih	10-Oct
The Nishīn al-Qanāṭir dike and the Tur'a Bulqīna	10 Bābih	12-Oct
Al-Faṣīl Dike (water to Tur'ā Ṭalkhā and Tur'a Minyat 'Abbād)	10 Bābih	12-Oct
Salmūn Dike (drains into the Rashīd branch)	26 Bābih	29-Oct
Salmūn Dike (drains into the Rashīd branch)	26 Bābih	29-Oct
Minṣal Samannūdiyya (drains into Baḥr al-Maḥalla)	5 Hatūr	7-Nov
The Tur'a Basāṭ (1/2 the water for al-Danjāwiyya)	5 Hatūr	7-Nov
Jisr Gharbiyya (drains to Nastrawiyya)	10 Hatūr	12-Nov
Jisr Farsh (drains al-Danjāwiyya into saltmarsh)		
Dikes (jusūr) of Shirījah	12 Tūt	15-Sep

Table 5. The partial record of rotations for the interior delta (see accompanying maps (**Figures 30, 31, 32**), following two pages)

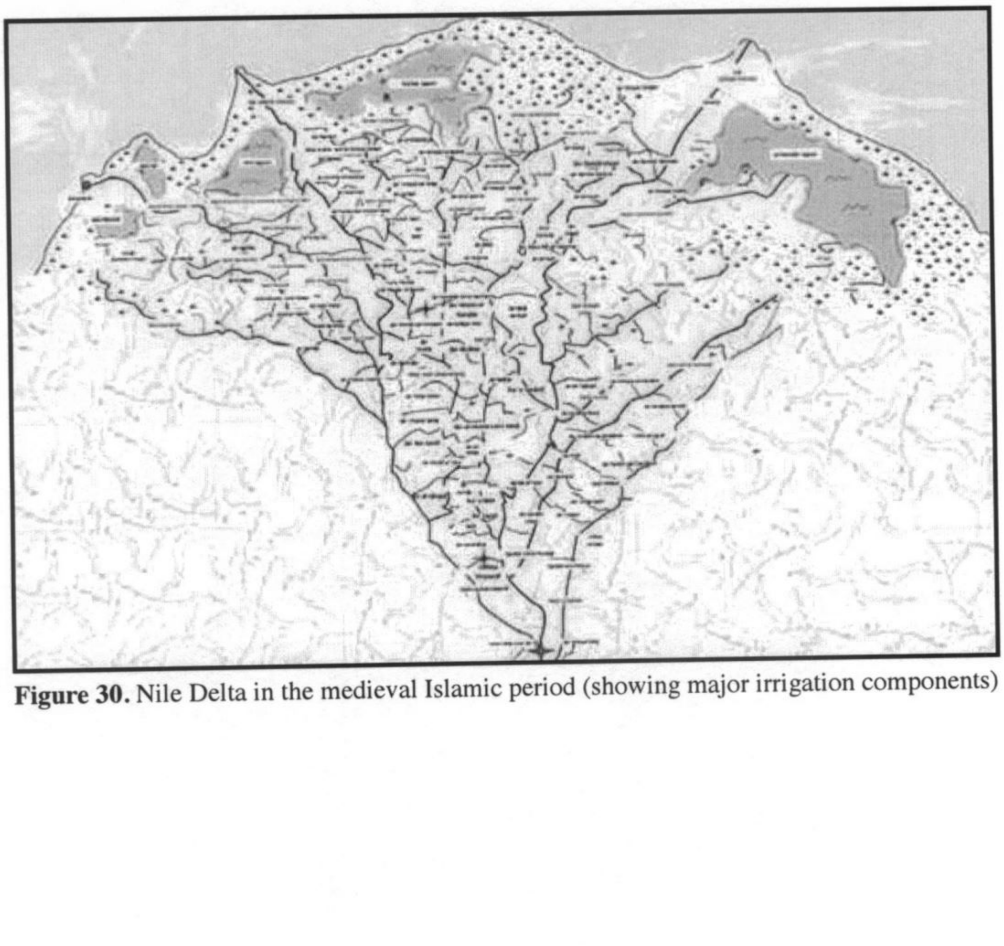


Figure 30. Nile Delta in the medieval Islamic period (showing major irrigation components)

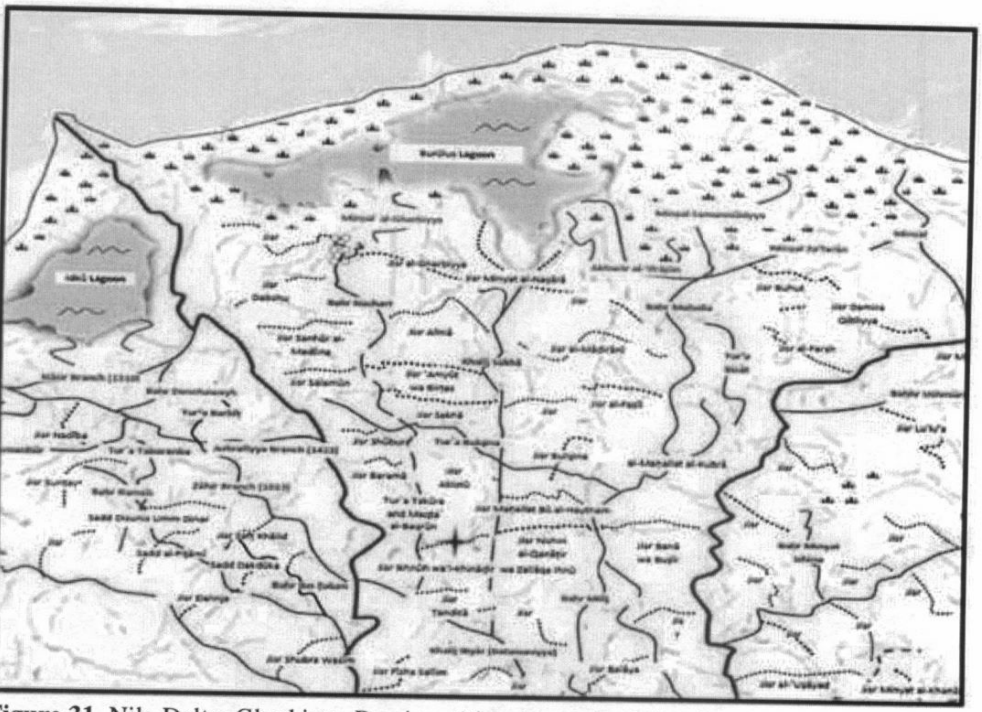


Figure 31. Nile Delta: Gharbiyya Province (showing major irrigation components)

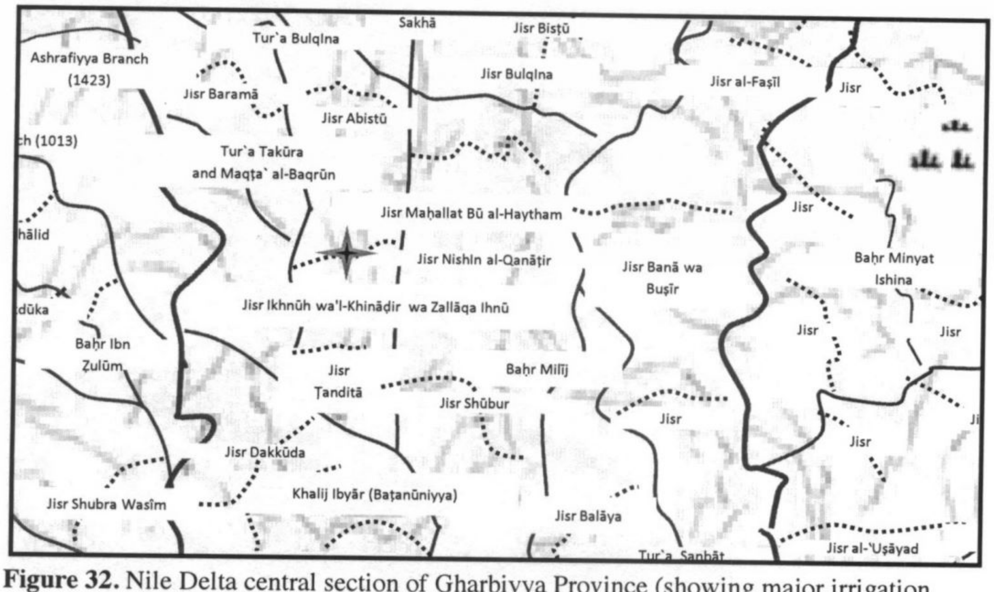
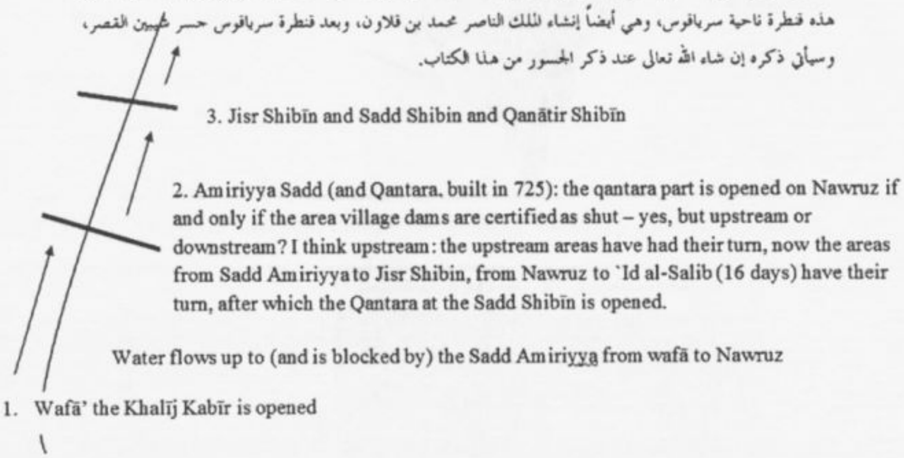


Figure 32. Nile Delta central section of Gharbiyya Province (showing major irrigation components)

Other sources record variations on this dating. For the Tur`at al-Bulqīna, there is an apparent conditional clause regarding its opening. Another version simply gives its opening as the Festival of the Cross, 17 Tūt: "Tur'a Balqīna (بلقينة) feeds the canals in the a number of bilāds in al-Gharbīya and is opened when the water rises on the 'Īd al-Ṣalīb. It comes out of the Khalīj al-Maḥalla at Balqīna and then it flows westward toward Sakhā, going through Dār al-Baqr, al-Mu'tamidīya, and Matbūl until it finally ends at Sakhā."[32]

قنطرة الأميرية: هذه القنطرة هي آخر ما على الخليج الكبير من القناطر بضواحي القاهرة، وهي تجاه الناحية المعروفة بالأميرية، فيما بينها وبين المطرية، أنشأها الملك الناصر محمد بن قلاون في سنة خمس وعشرين وسبعمائة، وعند هذه القنطرة ينسدّ ماء النيل إذا فتح الخليج عند وفاء زيادة النيل ست عشرة ذراعاً، فلا يزال الماء عند سدّ الأميرية هنا إلى يوم النوروز، فيخرج والي القاهرة، إليه ويشهد على مشايخ أهل الضواحي بتغليق أراضي نواحيهم بالريّ، ثم يُفتح هذا السدّ فيمرّ الماء إلى جسر شيبين القصر، ويسدّ عليه حتى يروى ما على جانبي الخليج من البلاد، فلا يزال الماء واقفاً عند سدّ شيبين إلى يوم عيد الصليب، وهو اليوم السابع عشر من النوروز، فيفتح حينئذ بعد شمول الريّ جميع تلك الأراضي، وليس بعد قنطرة الأميرية هذه قنطرة ناحية سرياقوس، وهي أيضاً إنشاء للملك الناصر محمد بن قلاون، وبعد قنطرة سرياقوس جسر شيبين القصر، وسيأتي ذكره إن شاء الله تعالى عند ذكر الجسور من هذا الكتاب.



The general parameters of rotation in simplified format and the Nile flood profile curve can then be seen for the Nile Delta as a whole in **Figure 33**.

By these means the same solution was found via the principle of rotating water usage. Ultimately the sophisticated Qanūn al-Riyy was tailored to solving hydraulic dilemmas like these.

[32] See Muḥammad Aḥmad 'Atā, Gharbiyya, 120. For the Jisr Sakhā, Page 54: it is noted as opened on the 8th of Babih – as above, where it is linked to the watering of the Tur'a al-Sakhāwiyya.

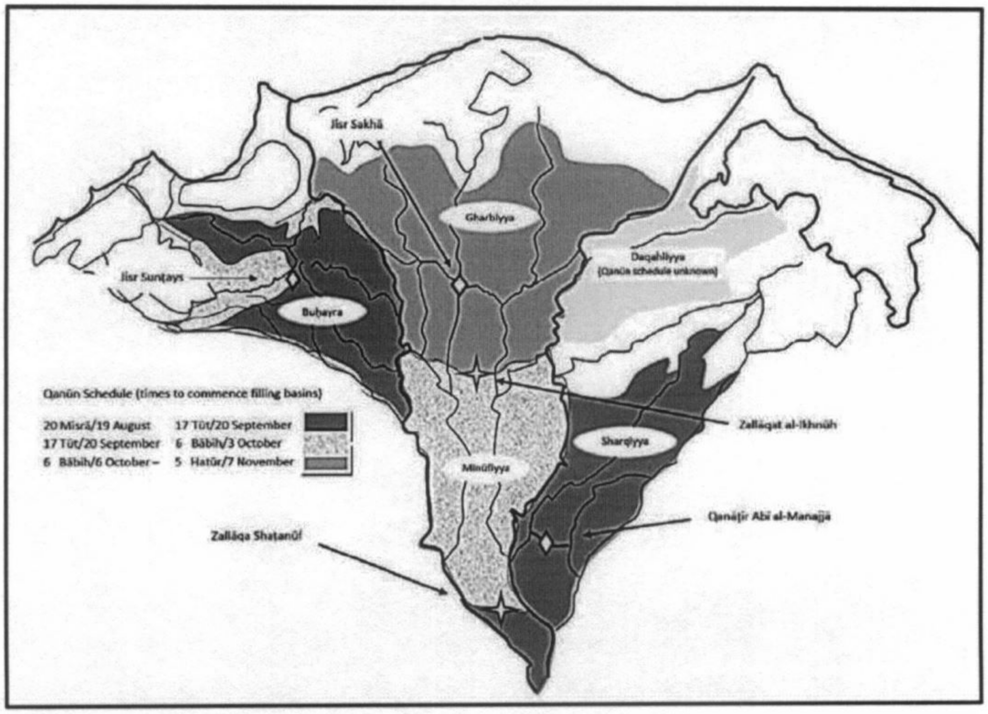


Figure 33. The Nile Delta and the Qanūn al-Riyy's rotation system

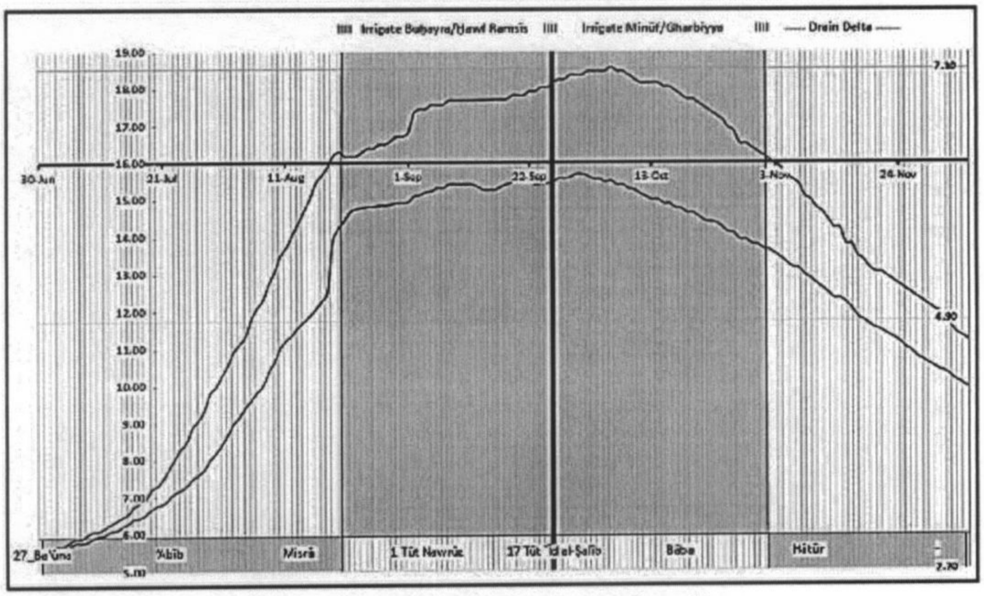


Figure 34. Nile Flood profiles (see rotation timing at top of graph)

Conclusion

Water Law turned out to be vital for the irrigation system of the Nile Delta. This terrain – *Triangular Landscape* vividly detailed by Katherine Blouin for the Roman period, had in fact since that time been crying out for it - as the old riverine system of nearby Nile channels collapsed from seven to two. Whenever exactly it had been established (our textual and archaeological evidence presented above suggests no earlier than the eleventh century CE) water law provided a protective screen against the temptations of collective misuse – misuse and overuse of canal-borne flood water during low Nile years. Collective misuse was born of the all too natural human tendency toward cooperative frailty when it came to the matter of disciplined and much-needed cooperation between villages during narrow flood windows. The failure of collective trust was in many ways was the very pitfall modeled by the familiar game of prisoners' dilemma, a game in which self-interested but rational actors inevitably score for themselves a long prison sentence – and that by dint simply applying reasoned calculation in a sound but solitary fashion. Water law provided for a sort of *common property regime* for the floodwater, a "common resource" (not "public good" – nor "private property") according to the particulars of the low Nile flood, with the law as the source of guidance for the authority of the provincial governor and his staff. The system that we studied via text, and modelled via computer simulation, seems to have provided a decent and relatively durable answer for Islamic Egypt's prosperity, though the later discovery (actually rediscovery) of the canal barrage's (qanāṭir) water raising powers in the Ayyubid period was to further enhance the security of this rule of law (qānūn al-riyy), which would lead to unprecedented system expansion and improvement for the Nile Delta in the early Mamluk period. But water law was the key underpinning, and its importance, along with that of the state in hydraulic matters, should be more widely understood. Brendan Haug's recent study of state authority in hydraulic matters ("Reintegrating the State into the Study of Egyptian Irrigation," *History Compass*, 2017), which covers the very long-term, is an encouraging step in this direction.

Muslims had no water law. This was the ruling of the European "experts" whose colonial mindsets have been analyzed by Timothy Mitchell and others. They had none in the nineteenth century - and it could not be imagined that they had ever even thought of such a thing. The colonials did in fact assign water law to Egypt's history, but they were careful to place it safely out of the reach of Islamic culture and ingenuity, tucking it far away in Greco-Roman antiquity. Those who happened to notice great irrigation works fallen to disuse, ruins of happier days before the arrival of the second plague pandemic (1348-1844 CE), assumed with comfortable ease that these, like hydraulic law and order, also dated back to the Romans and the Ptolemies. But the fact here too is that many of these ruins were likely were no older than the era of Sultan al-Nasir Muhammad's frenzy of skilled hydraulic construction in the early 1300s. And in this fashion the modern era has for a long time demonstrated rude disrespect for the hydraulic prowess of the Muslim engineer (muhandis) and the ordered innovations he produced. For the sake of future posterity, and with this water law in hand, we propose a more informed perspective, one whereby medieval Islamic Egypt whispers to these colonial souls, again and again:

Look on my Works, ye Mighty, and despair!